NETWORKS OF DISTRIBUTION AT THE MARGINS OF THE EMPIRE

LATE ANTIQUE GLASS VESSELS FROM THE LOWER DANUBE REGION

Anastasya Ivanova Cholakova

Institute of Archaeology
University College London
Thesis for Ph.D. in Archaeology
submitted December 2015
Declaration of authorship

I, Anastasya Ivanova Cholakova, confirm that the work presented in this thesis is my own. Where information has been derived from other sources, I confirm that this has been indicated in the thesis.

Date: 31.03.2016

Signed: [Signature]
ABSTRACT

The thesis aims to explore the distribution of glass in the Balkan territories of the late Roman and early Byzantine Empire based on an integrated research on glass vessels from the late 3rd to early 7th centuries AD from three site assemblages in present-day Bulgaria (Dichin, Odartsi, and Serdica). The category of artefacts, i.e. glass vessels, is deliberately chosen since they provide the opportunity to investigate both their ‘archaeology’ (in terms of vessel morpho-typology, decoration, manufacturing techniques, etc.) and their ‘chemistry’ (in terms of chemical composition) as two aspects of research which are not unconnected or contrasted but are complementary to each other.

Taking as a framework the model of division in the Roman and late antique glass industry, this study is focused not only on tracing the routes of glass supply from the primary production centres in the East Mediterranean to the Balkans but also on reconstructing the entire chains of distribution of raw glass and finished vessels to the consumers’ sites. Special attention is given to an attempt to identify inter-regional, regional and local networks (as a differentiation in their geographical directions, spatial scale, functional mechanisms, organization, technologies, etc.), and the stratified production and consumers’ needs related to them.

From a methodological point of view, the research is based on an integrated classification constructed from artefact research and scientific techniques for compositional characterization of glass (EPMA and LA-ICP-MS analyses). Approaches to technology, exchange, and distribution which have been originally formed in anthropological and economic theory are applied, combined with detailed understanding of particular historical and archaeological contexts.

The results point to a pattern of glass distribution corresponding to the overall technological and economic processes of Late Antiquity, with shifts in compositions, vessel manufacture and use in the early 6th c. AD when significant transformations took place in the Balkans.
CHAPTER I. INTRODUCTION AND BACKGROUND ......................27

I.1. Definition, aims, theoretical background and structure of the thesis .................................................................29

I.2. Late Antiquity: past historical developments and modern research perceptions ..............................................................39

I.2.1. The Lower Danube region during Late Antiquity ..................39

I.2.2. An overview of the general directions in the historiography of Late Antiquity .................................................................45

I.3. Models of economy and distribution in Late Antiquity ..................53

I.3.1. A review of the theoretical perspectives ..................................53

I.3.2. Glass studies in the context of the debates on late antique economy ..............................................................61

I.3.2.1. The current state of research .................................................62

I.3.2.2. Methodological and interpretative potential of glass studies ........65
CHAPTER II. METHODOLOGY AND APPROACHES ......................... 69

II.1. Methodology of an integrated classification................................. 71

II.1.1. Chemical glass composition as evidence in an archaeological enquiry... 72

II.1.2. Integrated classification and technological style/ chaîne opératoire approach........................................................................................................... 75

II.2. Analytical techniques and approaches....................................... 81

II.2.1. Laboratory based techniques.................................................. 81

II.2.1.1. Basic principles of the analytical techniques......................... 81

II.2.1.2. Particular instrumental settings and analytical runs............... 84

II.2.1.3. Data quality assessment ..................................................... 90

II.2.1.4. A comparison of EPMA and LA-ICP-MS data – evaluation of practical problems and interpretative significance ........................................ 103

II.2.2. Statistical techniques............................................................. 114

CHAPTER III. SITE GLASS ASSEMBLAGES – DICHIN ............. 119

III.1. Introduction.............................................................................. 121

III.1.1. The site................................................................................... 121

III.1.2. The vessel glass assemblage and sampling............................. 129

III.2. Groups in the Dichin assemblage........................................... 131

III.2.1. Engraved bowls – aqua-blue glass (Levantine I composition)........ 132

III.2.2. Bowls and beakers with fire-rounded rims – saturated green glass (HIT composition).................................................................................................................. 136

III.2.3. Beakers and bowls with cracked-off rims – yellow to dark-olive/ brown glass (HIMT composition)........................................................................................................ 140
III.2.4. Various vessel shapes – colourless/ nearly colourless glass (5th c. Mn-decolourised composition = Série 3.2.)........................................................................................................148

III.2.5. Stemmed goblets – various glass tints (6th c. composition = Série 2.1.)..............................................................................................................................................................164

III.2.6. Overview of the Dichin assemblage in terms of chemical glass compositions...........................................................................................................................................................................................................168

CHAPTER IV. SITE GLASS ASSEMBLAGES – ODARTSI ................. 175

IV.1. Introduction.........................................................................................................177

IV.1.1. The site.............................................................................................................177

IV.1.2. The vessel glass assemblage and sampling......................................................183

IV.2. Groups in the Odartsi assemblage.................................................................183

IV.2.1. Beakers with cracked-off rims – yellow to dark-olive/ brown glass (HIMT composition).................................................................................................................................188

IV.2.2. Stemmed goblets and oil lamps – various glass tints (6th c. composition = Série 2.1.)................................................................................................................................................................191

IV.2.3. Varia.............................................................................................................217

CHAPTER V. SITE GLASS ASSEMBLAGES – SERDICA .............. 227

V.1. Introduction........................................................................................................229

V.1.1. The site.............................................................................................................229

V.1.2. The vessel glass assemblage and sampling......................................................233

V.2. Groups in the Serdica assemblage.................................................................237
V.2.1. Unworked chunks/ a bowl – aqua-blue/ colourless glass (Levantine I composition) .................................................................................................................. 237

V.2.2. Cups with cracked-off rims – yellow to dark-olive/ brown glass (HIMT composition) .............................................................................................................................. 242

V.2.3. Cups with elaborate engraved/ cut decoration – colourless glass (Sb-decolourised composition) ........................................................................................................ 245

V.2.4. Vessels with blue trail decoration – colourless glass (5th c. Mn-decolourised composition = Série 3.2.) ........................................................................................................... 264

V.2.5. Stemmed goblets and oil lamps – various glass tints (6th c. composition = Série 2.1.) .............................................................................................................................. 267

V.2.6. Tank furnace production debris (mixed Sb- and Mn-decolourised composition) ............................................................................................................................. 270

V.2.7. *Varia* ................................................................................................................................. 273

CHAPTER VI. DISTRIBUTION NETWORKS: THEIR IDENTIFICATION AND INTERPRETATION .................................................................................................................. 281

VI.1. Inter-regional level of distribution networks ........................................................................... 283

VI.1.1. Inter-regional distribution of raw glass ................................................................................. 283

VI.1.1.1. Imported fresh raw glass and unworked debris of re-melting in secondary workshops: issues of differentiation ................................................................. 284

VI.1.1.2. Compositions of imported raw glass as indication of the inter-regional distribution networks reaching the Lower Danube region ........................................... 286

VI.1.2. Inter-regional distribution of finished vessels ....................................................................... 290

VI.1.2.1. Inter-regional movement of goods based on examples of finished glass vessels ................. 291
VI.1.2.2. Patterns of distribution of imported finished glass vessels in the Lower Danube region

VI.2. Regional level of distribution networks

VI.2.1. Summarised characteristics of the secondary glass manufacture in the Lower Danube region

VI.2.2. Circulation of unworked glass within the Lower Danube region

VI.2.2.1. Unworked glass supplies along the regional networks of distribution – possible compositional modifications?

VI.2.2.2. Compositions in circulation within the Lower Danube region based on examples of unworked glass

VI.2.3. Regional production and distribution of finished vessels

VI.3. Local level of distribution networks and evidence of local glass working

VI.3.1. Secondary glass working in the Lower Danube during Late Antiquity; interpreting the distribution networks of local scale

VI.3.2. Local production and distribution of finished vessels

VI.3.2.1. Late third – fifth century local-scale vessel manufacture in the Lower Danube region

VI.3.2.2. Sixth century local-scale vessel manufacture in the Lower Danube: the interpretation of the 6th c. glass composition in the context of distribution networks

CHAPTER VII. CONCLUSION AND FINAL WORDS
BIBLIOGRAPHY ................................................................................. 347

APPENDICES A. Images, graphs, and tables.................................................. 384

APPENDICES B. Analytical data..................................................................... 401

B.1. Standard measurements and data quality assessment

B.2. Compositional data
All drawings, photos, graphs and tables were produced by the author except in the cases when particular sources of the images are explicitly mentioned.

LIST OF FIGURES

CHAPTER I.

Fig. I.1. Schematic outline of the spatial scale of the distribution networks of glass at different levels in the Eastern Mediterranean during Late Antiquity.................................32

Fig. I.2. Position of the Lower Danube region within the broader Mediterranean........41

CHAPTER II.

Fig. II.1. Late Roman cage-cup and imitations of its decorative style produced using different and less-sophisticated manufacturing techniques........................................77

Fig. II.2. Comparison of the analytical runs’ repeatability expressed as RSD of the measurements of Corning A and B glass standards (major oxide suites).................................92

Fig. II.3. Comparison of the analytical runs’ trueness expressed as Δ rel. from the accepted reference values of Corning A and B glass standards (major oxide suites).....93

Fig. II.4. Comparison of the analytical runs’ repeatability expressed as RSD of the measurements of Corning A and B glass standards (full oxide suites).................................94

Fig. II.5. Comparison of the analytical runs’ trueness expressed as Δ rel. from the accepted reference values of Corning A and B glass standards (full oxide suites).........95

Fig. II.6. Uncertainty of the EPMA measurements of an actual sample (G 28)........98

Fig. II.7. Uncertainty of the EPMA measurements of an actual sample (G 12)........99

Fig. II.8. Alternative representations of the analytical runs’ repeatability calculated according to the accepted practices in the Wolfson Archaeological Science Laboratories
and IRAMAT……………………………………………………………………………………………………………..101

Fig. II.9. Working stage of the assessment of SrO results (EPMA and LA-ICP-MS) in Dichin samples plotted against identical iron oxide values.................................105

Fig. II.10. Serdica, Odartsi, and Dichin (only Levantine I glass) samples – comparison of the EPMA 2012, 2013(II), 2013(III) runs, and the LA-ICP-MS 2010, 2012, 2013 runs – TiO$_2$, MnO, Fe$_2$O$_3$, MgO.........................................................................................................................107

Fig. II.11. Serdica, Odartsi, and Dichin (only Levantine I glass) samples – comparison of the EPMA 2012, 2013(II), 2013(III) runs, and the LA-ICP-MS 2010, 2012, 2013 runs – Na$_2$O, Al$_2$O$_3$, CaO........................................................................................................................................108

Fig. II.12. HIMT and HIT samples (Dichin and Odartsi) – comparison of the EPMA 2007, 2010, 2012, 2013(I), 2013(II) runs, and the LA-ICP-MS 2010, 2012 runs – TiO$_2$, MnO, Fe$_2$O$_3$, MgO, Al$_2$O$_3$..................................................................................................................109

Fig. II.13. Dichin samples (5$^{th}$ c. Mn-decolourised and 6$^{th}$ c. compositions) – comparison of the EPMA 2010, 2013(II) runs, and the LA-ICP-MS 2010, 2012 runs – TiO$_2$, Fe$_2$O$_3$, MgO, MnO........................................................................................................................................111

Fig. II.14. Dichin samples (5$^{th}$ c. and 6$^{th}$ c. compositions) – comparison of the EPMA 2010, 2013(II) runs, and the LA-ICP-MS 2010, 2012 runs – Al$_2$O$_3$ and CaO........................................................................................................................................113

Fig. II.15. Outcome of the test PCA of a subset of samples from Dichin, Odartsi, and Serdica.........................................................................................................................115

CHAPTER III.

Fig. III.1. The fortified site near Dichin: general location and detail of the position of the hill on the south bank of the Rositsa River.........................................................122

Fig. III.2. Dichin: a view to the hill from East and a geodetic survey plan of the site...123

Fig. III.3. Dichin, Area F (the North-Western corner of the fortress)......................126

Fig. III.4. Dichin – fragments of bowls Isings 116 with wheel-engraved and cut
Fig. III.5. Levantine I glass samples from Dichin: scatter-graph of the individual EPMA measurements on each sample of manganese and potash levels.................................................................134

Fig. III.6. Dichin – fragments of bowls and beakers with fire-rounded rims made of HIT glass composition..........................................................................................................................137

Fig. III.7. Comparison of the MnO levels in the HIT samples (Dichin only) and the HIMT samples (Dichin, Odartsi, Serdica)...........................................................................................................138

Fig. III.8. Dichin – fragments of beakers and bowls with cracked-off rims made of HIMT glass composition..........................................................................................................................141

Fig. III.9. HIMT and HIT glass samples from the present dataset: alumina vs iron oxide, trace oxide ratios, copper oxide vs tin oxide..........................................................................................145

Fig. III.10. HIMT and HIT glass samples from the present dataset compared to published data: iron oxide vs titania...........................................................................................................146

Fig. III.11. HIMT and HIT glass samples from the present dataset compared to published data: iron oxide, magnesia and titania..........................................................................................147

Fig. III.12. Dichin – fragments of bowls of various shapes with engraved/ abraded decoration made of 5th c. Mn-decolourised glass composition..............................................................150

Fig. III.13. Dichin – fragments of vessels of various shapes and decoration made of 5th c. Mn-decolourised glass composition........................................................................................................152

Fig. III.14. 5th c. Mn-decolourised glass samples from the present dataset compared to published data from the Mediterranean and Britain: alumina vs lime..............................................157

Fig. III.15. The 5th c. Mn-decolourised glass samples from the present dataset: phosphate, strontium oxide, lime, and magnesia levels compared to the 6th c. composition..................................................158

Fig. III.16. The 5th c. Mn-decolourised glass samples from the present dataset: lime vs titania and trace oxide ratios compared to the 6th c. composition.........................................................161
CHAPTER IV.

Fig. IV.1. The hill-top fortified site near Odartsi: general location and a view from North-West..............................................................................................................................................178

Fig. IV.2. Odartsi – plan of the site and its surroundings..........................................................179

Fig. IV.3. Plan of the late Roman and early Byzantine fortification of Odartsi..........................180

Fig. IV.4. Odartsi – fragments of beakers with cracked-off rim and vessels made of HIMT glass composition...........................................................................................................................................189

Fig. IV.5. Odartsi – fragments of stemmed goblets Isings 111 and oil lamps made of 6th c. glass composition...............................................................................................................................................194

Fig. IV.6. 6th c. composition samples compared to the 5th c. Mn-decolourised composition from the present dataset: alumina vs lime..........................................................................................................................200

Fig. IV.7. 6th c. composition samples from the present dataset compared to data from Southern France and Northern Africa: iron oxide vs titania.................................................................201

Fig. IV.8. 6th c. composition and 5th c. Mn-decolourised samples: comparison of the iron oxide and manganese levels.............................................................................................................................202

Fig. IV.9. 6th c. composition and 5th c. Mn-decolourised samples from the present dataset: trace oxide ratios.................................................................................................................................204

Fig. IV.10. 6th c. composition from the present dataset compared to published data from other assemblages: alumina vs iron oxide..................................................................................................................205

Fig. IV.11. 6th c. composition samples from the present dataset compared to the data from Galeata and to 5th c. Mn-decolourised samples: manganese vs strontium oxide and barium oxide.............................................................................................................208
Fig. IV.12. 6th c. composition samples from the present dataset compared to the data from Galeata and the 5th c. Mn-decolourised samples: antimony oxide vs lead oxide and phosphate…………………………………………………………………………………………………………211

Fig. IV.13. Odartsi – varia: fragments of diverse vessels and a window pane piece belonging to different compositional groups………………………………………………………………………………………………………………218

Fig. IV.14. Alumina and lime concentrations of ODR 35 situated against the HIMTa, HIMTb, and HIT samples from the present dataset and Egypt II samples…………………..223

CHAPTER V.

Fig. V.1. The Roman and early Byzantine town Serdica: general location to the South of the Danube, and position of the fortified spaces in the original topography of the immediate area………………………………………………………………………………………………………………….230

Fig. V.2. The Roman and early Byzantine town of Serdica: general plan……………..……232

Fig. V.3. Location of Serdica within the modern city of Sofia, and the positions of two sub-urban sites which provided samples for the current study………………………………..234

Fig. V.4. A. The ‘MS 8-II’ site; B. The mausoleum in Lozenets, Sofia, with three sarcophagi inside one of the spaces…………………………………………………………………………………………………………………………235

Fig. V.5. Serdica – raw glass chunks and a bowl fragment with wheel-cut decoration made of Levantine I glass composition………………………………………………………………………………………………………………………….238

Fig. V.6. Levantine I glass samples from Serdica and Dichin: comparisons of the trace oxide ratios and alumina vs lime…………………………………………………………………………………………………………………………240

Fig. V.7. Levantine I glass samples from Serdica and Dichin: comparisons of potash, manganese and phosphate…………………………………………………………………………………………………………………………………………………241

Fig. V.8. Serdica and Samokov – fragments of cups/ bowls with cracked-off rims and an oil lamp base made of HIMT glass composition……………………………………………………………………………………………………………………………243

Fig. V.9. Serdica – fragments of vessels made of antimony decolourised glass…………246

Fig. V.10. Serdica – fragmented figured cage-cup made of Sb-decolourised (SER 26) and
cobalt-blue glass (SER 27), second half of the 4th c.................................250

**Fig. V.11.** Serdica – the cage-cup from the ‘Lozenets’ site and a cage-cup wall fragment from the ‘MS 8-II’ site, second half of the 4th c.................................................251

**Fig. V.12.** Analytical data of *diatretra* and two other engraved vessels made of Sb-decolourised glass – alumina vs lime and soda vs potash..................................................256

**Fig. V.13.** Analytical data of *diatretra* and two other engraved vessels made of Sb-decolourised glass – magnesia vs titania and antimony vs manganese.............................257

**Fig. V.14.** Modelling of the mixing of the colourless glass SER 26 and the hypothetical colorant (minor oxides)...........................................................................260

**Fig. V.15.** Modelling of the mixing of the colourless glass SER 26 and the hypothetical colorant (major oxides)...........................................................................261

**Fig. V.16.** Serdica – fragments of vessels and unworked chunks made of 5th c. Mn-decolourised composition.................................................................265

**Fig. V.17.** Serdica – fragments of stemmed goblet and oil lamps made of 6th c. glass composition.................................................................................................268

**Fig. V.18.** Serdica – unworked chunks of mixed Sb- and Mn-decolourised composition.................................................................271

**Fig. V.19.** Mixed Sb- and Mn-decolourised composition samples from the present dataset: antimony oxide vs lime and manganese vs alumina..........................272

**Fig. V.20.** Serdica – varia: fragments of unworked glass and diverse vessels belonging to different compositional groups.................................................................275

**Fig. V.21.** Trace oxide ratios of the six samples outliers from the Serdica assemblage situated against both major primary compositions distributed in the Lower Danube region in the 5th – 6th c.................................................................278

**CHAPTER VI.**

**Fig. VI.1.** Unworked chunks of glass – Dichin and Serdica..................................................284
**Fig. VI.2.** Fragments of bowls (samples G 18 and G 19) from Dichin – a likely case of a single production episode. ..........................297

**Fig. VI.3.** Examples of glasses with mixed Sb–Mn composition.........................305

**Fig. VI.4.** Main glass compositions in regional circulation during the 5th – early 7th c.: concentrations of transition metals and antimony oxide.................................307

**Fig. VI.5.** Examples of vessels decorated with blue trails........................................313

**Fig. VI.6.** Examples of vessels made of yellow-olive glass, presumably HIMT composition.................................................................315

**Fig. VI.7.** Map of the provinces in the Lower Danube region with indication of the sites providing evidence of secondary glass working activities (5th – 6th c.)......................323

**Fig. VI.8.** Fragments of cups, late 3rd – early 4th c., Telerig in North-Eastern Bulgaria.................................................................326

**Fig. VI.9.** Elevated and correlated concentrations of copper, lead, and cobalt oxides as evidence of contamination in the 6th c. glass composition........................................329

**Fig. VI.10.** The data from Fig. VI.9. plotted as a large-scale scatter-graph.................................................................330

**CHAPTER VII.**

**Fig. VII.1.** Schematic outline of the groups identified in the studied dataset arranged according to their associations to distribution networks at different spatial levels.................................................................339
LIST OF TABLES

CHAPTER II.

Table II.1. Sequence of the analytical runs (EPMA and LA-ICP-MS) of the Dichin set....86

Table II.2. Sequence of the analytical runs (EPMA and LA-ICP-MS) of the Odartsi set, and G 4 – a single sample from the ‘Samokov’ site.................................................................87

Table II.3. Sequence of the analytical runs (EPMA and LA-ICP-MS) of the Serdica set, and PLD 1 – a single sample from Philippopolis.................................................................88

CHAPTER III.

Table III.1. Average chemical composition of the Levantine I glass samples from Dichin.........................................................................................................................133

Table III.2. Average chemical composition of the HIT glass samples from Dichin.......138

Table III.3. Average chemical composition of all the HIMT glass samples in the present dataset..............................................................................................................143

Table III.4. Average chemical composition of all the 5th c. Mn-decolourised glass samples in the present dataset................................................................................156

CHAPTER IV.

Table IV.1. Average chemical composition of all the 6th c. glass samples in the present dataset..................................................................................................................200

Table IV.2. Diagnostic oxides of the cobalt-blue samples from Odarsti and Serdica compared to the samples from Iustiniana Prima.................................................................220

CHAPTER V.

Table V.1. Average chemical composition of the unworked chunks of Levantine I composition from Serdica........................................................................................................239
Table V.2. Average chemical composition of the Sb-decolourised samples from the present dataset (mean based on samples SER 28, SER 52, and G 84) ........................................ 247

Table V.3. Chemical compositions of the cage-cup from Serdica (‘Lozenets’ site) and the composition of the Co-blue layer of a patera fragment from the Corning Museum of Glass .................................................................................................................. 253

Table V.4. Average chemical composition of the unworked chunks found in the tank furnace at the ‘MS 8-II’ site in Serdica ................................................................................................................................. 272

Table V.5. Chemical composition of SER 25 (first row) compared to the composition of a ‘Kowalk’ beaker ............................................................................................................................................. 276

Table V.6. Chemical composition of the samples SER 44 and SER 45 compared to similar glasses from Iustiniana Prima ...................................................................................................................... 277
LIST OF APPENDICES

Appendix A.1. Map of the Balkan Peninsula presenting the administrative units (dioceses and provinciae) of Late Antiquity ..........................................................384

Appendix A.2. Distribution of vessel shapes and groups of manufacturing techniques juxtaposed with the main chemical glass compositions of the 5th and 6th c........386

Appendix A.3. Scatter graph of the trace oxide ratios of the main glass compositions identified in the present dataset ........................................................................388

Appendix A.4. Scatter graph of strontium oxide vs lime of the main glass compositions identified in the present dataset ........................................................................390

Appendix A.5. Scatter graph of potash vs magnesia of the main glass compositions identified in the present dataset ........................................................................392

Appendix A.6. Calculations of two theoretical schematic reconstructions of the Co-bearing colourant used in the cage-cup from Serdica ........................................394

Appendix A.7. Summary of the data quality assessment for each analytical run of EPMA and LA-ICP-MS measurements ................................................................. 396

Appendix A.8. Addenda to Chapter V ..........................................................398

Appendix B.1.1. Standard measurements and data quality assessment

Appendix B.1.2. Juxtaposition of EPMA and LA-ICP-MS results for the samples measured by both techniques

Appendix B.2.1. Levantine I glass composition

Appendix B.2.2. HIMT glass composition

Appendix B.2.3. HIT glass composition

Appendix B.2.4. Sb-decolourised glass composition
Appendix B.2.5. Mixed Sb–Mn glass composition

Appendix B.2.6. 5th c. Mn-decolourised glass composition

Appendix B.2.7. 6th c. glass composition

Appendix B.2.8. Varia
This study is located first and foremost within the research field of archaeology, regardless of the considerable amount of chemical formulae and numerals in most of the following chapters, as well as the occasional presence of terminology of scientific disciplines such as chemistry, geology or statistics. And archaeology as such is a fascinating branch of knowledge, which is ‘concerned with … the bric-a-brac washed up on the shores of modern times and left there as the social currents within which it was created have drained away’ (Giddens 1987, 357). Perhaps one of the main challenges of contemporary archaeological research is the endeavour to not just unearth, describe, measure and study that material ‘bric-a-brac’ survived into present, but also to create insights into those past ‘social currents’ that have ‘drained away’. In other words, to ask questions and look for answers about the people which had created and used the materials the remains of which we excavate and analyse today.

The present thesis is an attempt to explore not only the artefacts’ shapes, chemical compositions, dates, areas of distribution, etc., but also to inquire at least partially regarding the social identities and phenomena recognisable by the means of archaeological research.

There are many people to whom I am indebted and grateful for their advice, support, help, encouragement, and not least for their patience, which made possible the accomplishment of the present thesis. First of all, I would like to thank my supervisors Thilo Rehren and Ian Freestone to whom I owe a lot. The support of other past and present colleagues from the UCL Institute of Archaeology is also greatly appreciated – Kevin Reeves, Harriet White, Philip Connolly, Patrick Quinn, Andrew
Gardner, Kevin MacDonald, Ulrike Sommer, Marcos Martinón-Torres, Lisa Daniel as well as Bernard Gratuze (IRAMAT) and James Lankton. The advices of the two examiners – Patrick Degryse and John Shepherd – helped to improve the final text of this study.

The work on the present thesis was possible thanks to the NARNIA project (New Archaeological Research Network for Integrating Approaches to ancient materials study), European FP7 Marie Curie Initial Training Network, Grant agreement no. 265010, coordinated by Lina Kassianidou, University of Cyprus, with the support of Maria Dikomitou-Eliadou.

The Ministry of Culture – Republic of Bulgaria granted the sample export permits which allowed carrying out the analytical studies in London and Orleans. The Institute of Archaeology with Museum – Bulgarian Academy of Sciences provided institutional support for this PhD project, as well as a lot of personal help from many colleagues – Ventsislav Dinchev, Sergey Torbatov, Mario Ivanov, Lyudmil Vagalinski, Lyudmila Doncheva-Petkova, Evgenia Gencheva, Krastina Panayotova, as well as from colleagues from other museum institutions in Bulgaria – Pavlina Vladkova, Maya Martinova, Veselin Hadjiangelov, and Georgi Mavrov.

Many other people offered advice, helpful discussions, and friendly support during my work – Jennifer Price, Sylvia Fünfschilling, Sarah Paynter, Caroline Jackson, Justine Bayley, Sally Cottam, Mark Taylor, James Peake, Peter Cosyns, Mario da Cruz, Sonja Stamenković, Francesca Licenziati, Tanya Dzhanfezova, and Rossitsa Merdjanova.

Finally, but certainly not least, I am indebted to the entire community of B53 and the people related to it, and in particular to Fernanda Kalazich, Kristina Franke, Mainardo Gaudenzi Asinelli, David Larreina, Maninder Gill, Frederik Rademakers, Siran Liu, Pira Venunan, and Matt Phelps.
CHAPTER I

INTRODUCTION AND BACKGROUND

This First Chapter outlines the definition of the project, its spatial and chronological scope and the main research questions addressed in the thesis. The theoretical settings which provide a framework of the present study and the applied interpretative model are discussed as well. The second part of Chapter I summarises the historical background to the research, while also emphasising the importance of the evolving viewpoints within the general historiography of Late Antiquity. The third part is focused on certain particular aspects of trade and distribution of the period, in an attempt to delineate the methodological and the interpretative potential of glass studies within the broader context of the debates on the character of ancient economy.
I.1. Definition, aims, theoretical background and structure of the thesis

This thesis presents an insight into the supply and usage of glass during the centuries of Late Antiquity within the territories to the South of the Lower Danube frontier of the late Roman and early Byzantine Empire. The main purpose of the research is to delineate distribution, and immanently related to it production and consumption, as a multifaceted technological, economic and socio-cultural phenomenon of the epoch on the basis of an integrated study of vessel glass. Furthermore, an attempt is made to examine the combined archaeological and archaeometric evidence in the context of the regional historical processes, in order to enhance the interpretative significance of the primary data. In this regard, the following paragraphs present an introduction to the objectives, questions and theoretical basis of the research, and the overall layout of the thesis.

The present research is focused on an integrated study of glass vessels dated to Late Antiquity from the territory of modern Bulgaria. The spatial and chronological scope of the thesis is intended to correspond to the regional characteristics of this particular historical epoch, rather than to simply reflect formal geographical and temporal boundaries. The beginning of the unsettled but also quite distinctive period of Late Antiquity in the Balkans is marked by the reforms and overall socio-cultural and economic transformations of the Later Roman Empire in the end of the 3rd c. The upper chronological limit – the early 7th c. – is determined by the collapse of the imperial frontier and the virtual cessation of the early Byzantine presence in the Northern Balkans. During those centuries the Lower Danube territories of the Empire formed an administratively defined area – i.e. the provinces of Moesia Inferior and Scythia Minor (Appendix A.1.) At the same time, they became a scene of a specific political development and dynamic socio-economic and cultural changes, to a great
extent affected by the borderline position of the region to the South of the Danube limes. Accordingly, the present project explores the distribution of glass vessels during a well-defined period and region, namely the late 3rd – early 7th c. from the margins of the Empire in the Lower Danube region and the broader Eastern part of the Balkans (see Fig. I.2., page 41).

The fundamental theoretical framework of present-day multidisciplinary glass research stems from the widely accepted reconstruction of the overall organisation of this industry during the Roman period and Late Antiquity. Numerous analytical studies and archaeological discoveries of the last decades have changed the traditional view about glass being made from the constituent raw materials independently in each glass workshop, using local resources, and respectively, the same workshops also producing the finished objects. Instead, the remarkably consistent glass chemical compositions found throughout the Empire imply a different kind of organisation – a model of division of the overall industry in two distinct stages. This hierarchically functioning system consists of primary glass making associated with few large-scale production sites, attested so far in Egypt and Syro-Palestine, and manufacturing of finished object, i.e. secondary glass working, taking place in a wide range of smaller workshops across the Empire (Nenna et al. 1997; Foy and Nenna 2001; Freestone et al. 2002a; Freestone 2006). Such a two-stage model presumes the supply of raw glass (as unworked chunks) from the large-scale primary centres to numerous secondary workshops where the glass was only re-melted (and/or recycled cullet was used). At the same time, even if divided into two clearly different stages, glass production should have been acting as an integral structure of technological, economic, and social interactions, closely related to distribution and supply as the most dynamic sectors of the ancient economy. Surprisingly, the historical sources of that time are rather silent about such a complex phenomenon, except for certain fragmented and debatable legislative evidence (cf. Whitehouse 2004; Barag 2005). It is mostly the combined archaeological and compositional analysis of glass finds that can reveal the directions, scale and nature of these interactions.

In agreement with the theoretical background, the main objective of the present thesis is to characterise the distribution of glass in the Lower Danube region
through the integration of conventional archaeological artefact study and scientific analysis, while also addressing questions of glass production and usage. The choice of the category of studied materials, i.e. glass vessels, is deliberate since they provide the opportunity to investigate both their ‘archaeology’ (in terms of vessel shapes, decoration, manufacturing, etc.) and their ‘chemistry’ (in terms of chemical composition). The aim of this integrated approach is to avoid the construction of descriptive, static, detached and therefore inevitably incomplete separate patterns of vessel morpho-typology and chemical glass compositions, respectively. Instead, archaeological and archaeometric evidence is considered as interlinked and complementary to each other, since both vessel manufacture and glass making (and compositional modification) are rooted in the broader domain of technology. The purpose of this study is to combine them in order to outline an interpretative picture, or, in other words, to progress from the formal labelling of data to examining the technological and socio-cultural phenomena behind the data. In this way, it is hoped that the present project not only presents a regional view of late antique glass, but also provides a particular insight into the complex social processes of transformations at the edges of political territories and historical periods.

Therefore, an intrinsic part of the research objective is to achieve a certain explanatory social perspective of the studied dataset. The leading reasoning used here originates in the theory of interpretive sociology (cf. Pressler and Dasilva 1996; Johnsen and Olsen 1992), and implies that understanding of past phenomena, as opposed to their mere empirical description, involves accessing the meaning which the actual participants assigned to them. When this theoretical rationale is transposed into the setting of the present project, the circulation of late antique glass in the Lower Danube region needs to be regarded in relation to the system of notions and attitudes towards material objects of the ancient society, which was the actual user of these artefacts. Therefore, the implementation of the main objective of this study requires not only a theoretical framework but also an explanatory model. Such a model of interpretation would allow for a more adequate correspondence between the two seeming opposites – the past socio-cultural perceptions of the late antique population in the Lower Danube region and the methodological approaches of present-day
Fig. I.1. Schematic outline of the spatial scale of the distribution networks of glass at different levels in the Eastern Mediterranean during Late Antiquity (after Cholakova 2014). Long-distance inter-regional, regional, and smallest local networks differ not only in terms of spatial dimensions but also in their economic meaning and mechanisms of functioning. Geographical positions of the three sites in the Balkans which provided glass assemblages for the present project (after Dinchev et al. 2009; http://d-maps.com; http://blog.geographydirections.com/ tag/map/ accessed November 2015).
research.

The explanatory model adopted and developed here takes the socio-economic phenomenon of distribution as its basics. The tools of artefact study and compositional analysis have a great potential to trace the circulation of glass – both as raw material and as finished objects (cf. Whitehouse 2003). Nevertheless, the intention to understand the meaning of this circulation for the ancient society implies that one should certainly look for evidence of physical movement of goods in terms of distribution patterns, but also needs to address the problem of the socio-economic reasons and underlying mechanisms of this movement.

Accompanied, networks of distribution are the main focus and the explanatory model of the present research, to a certain extent influenced by the theory of economic anthropology and economic history. Glass vessels were only a small part of the perishable and non-perishable goods that travelled along the late antique distribution networks but they are probably among the most suitable and responsive archaeological material for reconstruction and interpretation of these networks. As mentioned above, the supposed division of glass production in two distinct stages already indicates the importance of actively used routes of raw glass procurement. Furthermore, the specialised nature of the secondary glass working, as a commercialised craft, separated from certain other nearly non-exchangeable productions of Late Antiquity at the domestic level of self-sufficiency (e.g. basic hand-built pottery manufacture, small-scale metalwork upkeep), also must have required particular forms of distribution of the finished objects.

A wide range of questions are addressed when networks of distribution are identified based on glass vessel site collections, from a ‘retrospective’ point of view, i.e. when consumption site assemblages are studied as main evidence of distribution. A very simple scheme would assume an essential chain beginning from the primary raw glass production centre, through the secondary glass vessel manufacturing workshop(s), to the consumer end – i.e. the places of use of the finished products. Nevertheless, such a general outline has numerous aspects, in which these networks of
distribution varied and reflected technological, economic, and socio-cultural diversity and changes.

One of the leading criteria for defining different networks of distribution of glass vessels in this research is the *spatial scale* of these systems of interaction. The stratification of inter-regional, region, and local levels is well-accepted in works devoted to ancient trade. Distances and time of transit are used as discriminants in this type of research (cf. Morrisson 2012a), and they can be a very efficient tool in glass studies as well. In particular, the analyses of chemical glass makeup provide a unique opportunity to trace the networks of inter-regional distribution through linking different compositional glass groups attested across the Empire to certain areas or locations of primary production on the basis of characteristics of the glassmaking sands (Fig. I.1.).

However, the present project is not intended to merely conclude that the Lower Danube territories of the Empire apparently received their glass supplies from one or the other of the primary East Mediterranean glassmaking centres in Egypt and the Levant, as demonstrated by the compositional data. Such a simplified picture (admitting also the existing uncertainties regarding the actual locations of some of the primary centres) would overlook many other processes, given that the consumption site glass assemblages are mostly reflections of procurement and usage of finished objects, as opposed to unworked raw glass. Respectively, these finished objects (i.e. glass vessels) were made in secondary manufacturing workshops, with various geographical locations, various ways of provision of glass, and various levels of organisation and craftsmanship. Therefore, a full understanding of distribution networks would ideally include recognition of these secondary centres, holding ‘intermediate’ positions within the entire chain, as actual places of origin of the glass objects found at consumption sites (Fig. I.1.).

If such a problem is addressed only by means of compositional analysis it may not be adequately resolved. At least in theory, a small workshop for mass-produced vessels in the Balkans may be supplied with the same primary glass as a bigger atelier in the Levant which manufactured better quality glassware for higher consumer
demands and wider distribution. Distinguishing between the products of two such centres found in the same site assemblage has a great interpretative importance – beyond a doubt, a single decorated and eye-catching vessel brought from far afield must have had a different meaning for its owner, compared to the commonly available simple glassware from the local workshop. Accessing the significance of this differentiation would be possible only through the study of the artefact characteristics of the vessels, since both groups would be compositionally very close or even identical. An intricate pattern of distribution networks (both of raw glass and finished objects) can be revealed only by an integrated study of shapes, techniques of vessel manufacture, finishing and decoration, and compositional analysis. In terms of spatial scale, this model allows differentiating imports (and possibly their origin) and locally/regionally manufactured and distributed vessels.

Furthermore, another important aspect of the networks should be outlined, i.e. the socio-economic mechanisms which underlie the movement of goods. Clearly, the commercial mechanisms of trade, market type demand–supply logic and profit motive had a decisive role in the distribution of glass. However, non-commercial reasons should not be ignored. The non-utilitarian social meaning of the vessels as gifts, religious souvenirs, personal possessions, symbols of status or hierarchical relations determined a considerable part of the networks, especially the long-distance distribution of luxurious glass in Late Antiquity. At the same time, certain state-led networks may have facilitated the supply of big volumes of raw glass, and this protected or even monopolised distribution should not be seen as controlled by free market mechanisms. Finally, a detailed diachronic study of the networks can recognise processes of the overall economic development of the region, and the quite expected blurring between different types of movement of glass.

The explanatory model of distribution networks of glass in the Lower Danube region in Late Antiquity defines the specific research questions or tasks of this project. They are interlinked and complementary to each other but, at the same time, the sequence of their particular discussions represents the overall logic of the present study. The following three questions form the general structure of the thesis:
• How should the available dataset of primary evidence (i.e. glass finds identified by artefact characteristics, context, date, and chemical composition) be organised in order to outline a meaningful and interpretable pattern of groups both within and between the studied site assemblages?

• Which levels and types of distribution networks (as recognised by their spatial scale and socio-economic mechanisms, according to the adopted explanatory model) can be distinguished in the outlined pattern of groups within the primary dataset?

• And finally, to what extent is it plausible to relate the development and functions of the identified distribution networks to known social and historical phenomena of the period?

The outlined questions follow the line of reasoning commonly applied in archaeological research which strives to examine the fragmented and ‘mute’ material remains, often referred to as ‘archaeological record’ in their aspect of ‘communicative’ interpretable evidence of past societies and their traditions, knowledge, developments, etc. The empirically constructed pattern of differences and similarities, as defined by certain criteria, within the archaeological record is related to a meaningful pattern of social practices (technological, economic, ritual, etc.). On the basis of these practices, in turn, more general socio-cultural identities of the past can be inferred (cf. Gardner 2004), or even direct interpretations of historically known phenomena could be constructed.

The present project focused on particular glass assemblages excavated at three late antique sites in Bulgaria (Fig. I.1.). Dichin is a fortified settlement of semi-urban type in the province of Moesia Inferior, dated to ca AD 410-580. It was excavated from 1996 to 2003 in the framework of a joint British-Bulgarian programme (Dinchev et al., 2009; Rehren and Cholakova 2014), and offers materials from well-stratified contexts. Only part of the entire glass assemblage from Dichin (i.e. the finds excavated at the
North-Western area) was available for chemical analysis in the present project*. Odartsi is comparable to Dichin in its archaeological site characteristics but has a more complex stratigraphy and a longer period of occupation, spanning from the early 4th c. to ca AD 615. Likewise Dichin, it is situated in a frontier area to the South of the Lower Danube, in the province of Scythia Minor. The site was excavated by a Polish-Bulgarian team from 1969 to 1992 (Dončeva-Petkova and Torbatov 2001; Torbatov 2002a). Serdica is the Roman town which precedes the present-day Bulgarian capital Sofia. During Late Antiquity Serdica was the capital of the province of Dacia Mediterranea. A recent rescue project (conducted from 2010 to 2012; Ivanov 2013; Ivanov in press) in a large area of the centre of the city provided a variety of glass finds. A selected set of them, and a few more fragments from other related sites, were studied in the present project as comparative material, in order to extend and complement the conclusions based on the Dichin and Odartsi assemblages.

The primary dataset of the current study comprises 199 samples. Most of them were taken from vessel fragments which allow identification of the original shapes; a few complementary samples come from unworked glass chunks, production waste, and window panes. The majority of the materials was found in dwelling contexts, even though not all finds are assigned to the primary domestic setting of their use, but some were re-deposited in secondary contexts (e.g. fill layers, mixed disturbed contexts, dump deposits, etc.). Additionally, several samples come from secondary glass working installations and production debris assemblages, as well as a single exceptional case from a burial complex.

Finally, the structure of the thesis can be briefly outlined as follows. The First Chapter provides an introduction to the project, and presents the parameters, aims, and theoretical background of the research. A summarised overview of the history of the Lower Danube region in Late Antiquity and a survey of the general historiography of the period are followed by a discussion of the late antique economy and distribution. The Second Chapter presents the methodology and approaches of the research. The

* The remaining part of the glass finds from Dichin is included in a parallel research project for compositional analysis in Nottingham University (Smith 2011).
reasoning of an integrated classification of the primary dataset is justified; special attention is given to the analytical techniques and the evaluation of the data quality.

The three site glass assemblages from Dichin, Odartsi, and Serdica are discussed in detail in Chapters Three, Four, and Five. These parts of the thesis have an identical internal structure, consisting of short introductions to the sites and their archaeological characteristics, followed by thorough presentations of the groups defined within the assemblages. Chapter Six summarises the classification of the three assemblages and delineates the distribution networks of glass attested in the Lower Danube region based on the present dataset.

An overview of the conclusions and the perspectives of future work are given in the closing Chapter Seven, followed by the Appendices with illustrations, graphs, tables, and the primary analytical data.
I.2. Late Antiquity: past historical developments and modern research perceptions

The political events, their immediate consequences, and more long-term social processes in the Lower Danube region in the late 3rd – early 7th c. construct the regional historical narrative of Late Antiquity. The representation created through interpretation of preserved textual sources delineates the most apparent aspects of the period. At the same time, socio-historical developments are closely associated with the formation of the archaeological record. These two facets of the past realities are interlinked and yet, archaeology is more than a mere material chronicle of history. Understanding and thorough interpretation of late antique archaeological evidence involves awareness of the particular historical context, as well as a certain level of consciousness about the character of the modern research viewpoint. The following sections outline the historical background to the present thesis and provide an insight into the changing perceptions of Late Antiquity.

I.2.1. The Lower Danube region during Late Antiquity

The Northern Balkan region situated to the South of the Lower Danube River (Fig. I.2.) became part of the Roman state as early as the beginning of the 1st c. AD. During the following three centuries of the Principate this area was fully integrated in the political and economic structure of the Empire, and developed in line with the overall provincial Roman socio-cultural traditions. However, its geographical location as a distant border region of Rome had a decisive significance during the mid-3rd c. when the Eastern Balkans suffered from the first large-scale incursions of barbarian tribes of the Goths, Carps and Vandals, mostly known for the defeat of the Roman army in the battle of Abritus in AD 251 (cf. Lozanov 2015).
The devastations of the provinces in the Lower Danube region were only part of the general political and economic crisis of the Empire during the 3rd c. Its overcoming led to profound reforms which marked the beginning of the late antique period and the dawn of wider processes of transformations of the earlier Roman world towards the realities of the Middle Ages.

The establishment of a new political order – the Dominate – initiated by Diocletian (284-305) had significant implications in the Balkans. The beginning of the overall reforms was marked earlier by Aurelian (270-275) with the withdrawal of the Empire from the territories to the North of the Lower Danube, and the foundation of a new province of Dacia Aureliana in the Balkans. This political and strategic act was followed by the introduction of an entirely new administrative division started by Diocletian and completed in the early 4th c. which re-shaped the whole structure of governance in the Balkans. This new system of dioceses and provinces from the late 3rd – early 4th c. remained functioning, with certain changes, until the early 7th c. (Appendix A.1.). The region to the South of the Lower Danube was subdivided into the provinces of Moesia Prima, Dacia Ripensis, Moesia Secunda (also called Moesia Inferior), and Scythia Minor (cf. Dumanov 2015). Another important part of the reforms during the reign of Constantine I the Great (306-337) consisted of changes in the military system, which was separated from the civil government. Two main categories of units were introduced – limitanei (borderline troops or garrison soldiers) and comitatenses (interior troops or mobile field units). This reform opened the way for further modifications during the following two centuries and a gradual transfer of military duties to the provincial civil population and different ethnic groups, as evident in the Balkans (Dinchev 2006).

The defence of the Balkan provinces and the Lower Danube limes of the Empire received a new significance with the establishment of the new capital of the Empire – Constantinople – in AD 330 in the region. The city of Constantine I the Great became not only the main political centre of the state but also a major economic hub of commerce, long distance trade, crafts, and consumption. In parallel and related to the growth of the new capital, the Orthodox Church gradually consolidated itself as a powerful authority. This process began with the proclamation of religious tolerance to
Fig. 1.2. Position of the Lower Danube region within the broader Mediterranean and the locations of the late antique provinces Moesia Inferior and Scythia Minor (1), Caria and Insulae (2), and Cyprus (3) included during the 6th c. in quaeestura exercitus (after Ward-Perkins 2001b).
the Christians (AD 313 – Constantine’s edict), and evolved later into the total dominance of the Christian doctrine as the only religion of the state (AD 380 – Emperor Theodosius’s edict). The Lower Danube region was largely included in this development, with a well-established hierarchy of the local clerical administration and numerous examples of early Christian architecture (e.g. Chaneva-Dechevska 1999). With its political and economic strength, the Church often remained the only stable formal social system during the turbulent centuries of Late Antiquity in the Eastern Balkans, taking some of the functions of the earlier municipal institutions or sometimes even those of the official central government (cf. Dinchev 2014).

The history of the Lower Danube region during the early 4th – early 7th c. is marked by a series of military conflicts and political upheavals. In the early 4th c. the Balkans became a scene of the rivalry and of certain episodes of the civil war between the tetrarchs. The confrontation finally led to the victory of Constantine I who in AD 324 became the sole ruler of the Empire. The following years of peace, prosperity, and strengthening of the Balkan provinces came to an end in the last quarter of the 4th c. The central government of Valens (364-378) was unable to keep the agreement for food supplies for the Goths who were allowed to settle to the South of the Danube. As a result, the outbreak of the Gothic war (AD 364-382) had catastrophic consequences for the Empire (Heather 1996, 2006). The defeat of the Empire at Adrianople and the death of Emperor Valens on the battlefield (AD 378) were followed by major devastations of the Balkan region, and the settlement infrastructure of the 4th c. was never restored again to the same scale. The long-term presence of different Gothic enclaves in Moesia Inferior and the adjacent provinces became an important factor of the political and socio-economic development of the Lower Danube. They were integrated into the military system of the Empire as foederati – military troops of barbarian tribes subsidized by the central government in exchange for their support of the border defence. Nevertheless, the Empire never achieved a stable political control over those foederati groups which until the late 5th – early 6th c. kept their privileged position detached from the central military authorities.

The peace in the Balkans was restored during the reign of Theodosius I. After his death in AD 395 the Roman Empire was nominally split in Western and Eastern
parts (Blockley 1997). Arcadius, the ruler of the East faced the next uprising of the Goths settled within the territories of the Empire (e.g. Heather 1991). However, the attacks of the next phase of the Migration period – the Huns invasions, became even more threatening, and ruined considerable parts of the Lower Danube region. The most massive incursion was in AD 447 when nearly all the Balkans was devastated (Velkov 1979). The collapse of Attila’s Empire after his death in AD 453 caused another series of intrusions and movement of different tribes to the South of the Danube, including a raid of Attila’s son in Moesia Inferior dated to ca AD 470 (Dinchev et al. 2009). The end of the 5th c. was the time of another culmination of the foederati danger in the Balkans. Different Ostrogoth troops entered a long-term military conflict between each other and against the central government of the Emperors Leo I (474-475) and Zeno (476-491), until AD 488 when the army of the Ostrogoth ruler Theodoric Amal left Moesia Inferior and headed to Italy (Heather 2006).

Despite certain events in the early 6th c. a generally less unsettled period in the Balkans started with the reign of Anastasius I (491-518) and continued with the reforms of Justinian I the Great (527-565). The increased military potential and the political stability of the Empire during the first half of the 6th c. (Whitby 2001) resulted in measures for strengthening the control over the Lower Danube region. As part of it, reconstructions of many of the defences were undertaken (e.g. Dinchev 2006), as well as certain attempts to support the logistic of the borderline troops. In AD 536 an entirely new and unique administrative unit was established by Justinian – the so called quaestura exercitus. Unfortunately, only partial information about this formation has survived in the preserved sources. It connected in an exceptional way two of the most devastated borderline Balkan provinces – Moesia Inferior and Scythia Minor, with quite distant East Mediterranean territories, i.e. Cyprus, Caria, and some of the Cycladic Islands (Fig. I.2.; Jones 1964; recently Rizos in press). It is known that the seat of the quaestor exercitus, or ‘Prefect of Scythia’ was based in Odessus, present-day Varna, on the Black Sea coast of Moesia Inferior (Appendix A.1.). The supposed aim of this inter-provincial unit was to ensure the supplies of staple food (annona militaris) and financial support to the frontier defence along the Lower Danube (Torbatov 1997). Its functioning is indirectly attested by a concentration of
lead seals found at the sites in Scythia Minor (Curta 2002) and by the patterns of amphorae distribution in the Northern Balkans (Karagiorgou 2001; Curta 2016). The last reliable documental information about the *quaestura* is dated to 575 but it is assumed that the institution kept its functions even later (Torbatov 1997). The commonly accepted interpretation of this peculiar administrative unit is that it was mostly aimed at compensating for the shortage of locally produced food resources in the Lower Danube region, which resulted from the devastation and the overall political insecurity due to the barbarian attacks. In this way, the state tried to ensure the necessary provisions through centrally controlled imports from the Mediterranean. The main implication of such an interpretation of the *quaestura exercitus* is that apparently a vast, well-organised and state-led long-distance network of distribution existed in the Lower Danube region. Significantly, its economic mechanism should be defined as redistributive and non-commercial. At the same time, this centrally maintained and run infrastructure certainly provided space for parallel distribution of other kinds of goods (e.g. through shared use of transport infrastructure, and possibly through tax exemptions as well – Karagiorgou 2001, 155; cf. Whittaker 1983), which could be seen as commercial trade, although not ruled by market-type mechanisms.

Nevertheless, the increasing invasions of the Avars, the Slavs, and various other barbarian tribes during the 6th c. finally had a crucial impact on the Northern Balkan limes of the Empire. Despite all the logistic measures and the defence operations these different groups demonstrated a growing military power and a clear intention to find new territories for permanent settling to the South of the Danube. The process led to substantial and irreversible ethnic and cultural changes. During the last quarter of the 6th c. most of the late antique settlements in the Northern Balkans were abandoned. (Whitby 2001). The imperial frontier practically ceased to exist by the early 7th c. or by the end of the reign of Heraclius (610-640). Afterwards, completely different historical and societal phenomena arose with the formation of the early medieval Proto-Bulgarian political entity in the last quarter of the 7th c. Interestingly, there is quite little definite material evidence so far dated to the decennia prior the 8th c. about settled presence of the new ethnic groups, which suggests a certain hiatus during the
7th c. that further underlines the differences between written history and archaeology-based narratives of the past.

Inevitably, all these political events and transformations of the population in the region have had a significant effect on the overall socio-cultural development of the region during the early 4th – early 7th c., and hence have been reflected in the archaeological record. The overall insecurity during Late Antiquity dramatically changed the settlement network of the Balkan provinces, and the fortified sites well-suited for defence (but not necessarily having an exclusively military character) became probably the most widespread type of settlement during the 5th – early 7th c. These sites partially adopted some of the administrative and economic functions of the earlier Roman urban centres, but at the same time the household traditions and everyday life of their inhabitants were quite different, which is the reason for the definition ‘semi-urban settlements’ (Dinchev 2006). Nevertheless, many provincial towns continued their existence until the late 6th – early 7th c. despite of the general decline, but their legal status was considerably changed, compared to the Roman period (Velkov 1977).

Interestingly, the centuries of Late Antiquity in the studied region were not marked by an overall downturn or decline of the local crafts, and numerous small workshops, including for glass working, are well attested archaeologically (Cholakova 2008). However, the current data suggest that these were mostly small-scale centres. In particular during the 5th – 6th c., numerous not too skilful workshops existed and produced glass items to satisfy the immediate needs of the regional population with unsophisticated consumer standards and demands (see Section VI.3.).

I.2.2. An overview of the general directions in the historiography of Late Antiquity

The period of Late Antiquity has been attracting with varying intensity the attention of scholars over time, and a diversity of viewpoints and opinions exist in the literature. Although no strict and unifying chronological or geographical boundaries can be pointed out, it is generally accepted that the major historical and socio-cultural
phenomena which took place within the post-Roman world and beyond it started developing around the second half of the third century, a moment of significant changes in the Empire. Similarly, fundamental new realities were formed throughout the seventh and eighth centuries (and even later), delineating the end of the period (Bowersock et al. 1999). Even a brief look at some of the most important studies on Late Antiquity can clearly reveal the extensive evolution of the researchers’ understanding and approaches. The period was initially seen in the historiography as a phase of sharp historical periodization marked by certain political events, but later a perception of longer processes of transformations and interactions was ascribed to it, and notions such as ‘uniqueness’, ‘legacy’, and ‘fascination’ became relevant (recently Johnson 2012, xv-xvi; Clark 2011, 3; Marcone 2008).

A thorough review of the literature on late antique history, culture and archaeology is beyond the scope of the present project, which is focused mostly on a specific region and particular issues of distribution and production as elements of the economy (see Section I.3.). However, in an attempt to situate the research within the broader framework of late antique studies, certain general historiographical directions have to be outlined, albeit most of the facts are well known.

Back in the second half of the eighteenth century the European historiography formulated the concept of ‘decline and fall’ in regard to post-Roman times (Gibbon 1994, originally published in 1776-1788). The famous work of E. Gibbon is defined as a ‘historical masterpiece’ (Hingley 2000, 29), a ‘standard early-modern touchstone for students of Late Antiquity’ (Johnson 2012, xii), ‘sole great narrative of that period in any language’ (Ando 2009, 60). Ironically, it seems that the most important influence of Gibbon’s historic representation is, on one hand, the creation of the concept about Rome’s fall and decline as a classical paradigm for every decline (Marcone 2008), and on the other hand, shaping the following generations of research through rejection of this ‘unapologetic link between ‘late’ and ‘decline’ (Rousseau 2009, xix)∗.

∗ The importance of Gibbon’s eighteenth century understanding and its repeated and still ongoing disproval more than two centuries later is evident even in some examples in the recent Anglophone literature (e.g. Clark 2011).
Most of the nineteenth century approaches, however, were still strongly influenced by the ideas of decline but also by the notion of change – probably as a reflection of political events of that time at the perceptions of historiography and art (Rebenich 2009). Particularly interesting was the tendency to see analogies between the ‘declines of the Empires’ in late Victorian and Edwardian Britain in an attempt to use history as a provider of ethical lessons (Hingley 2000, 31-32).

At the beginning of the twentieth century, within the field of art history (Riegl 1901), Late Antiquity was accepted as an autonomous phenomenon with self-defined characteristics, and rather wide chronological limits up to the eighth century (Rebenich 2009; Marcone 2008). A similar emphasis on continuity and the existence of common Mediterranean trade networks regardless of political disruptions was identified as an economic phenomenon of the period (Pirenne 1939). In this way, gradually, the notion of a ‘long’ Late Antiquity started to emerge, even if the persisting historiographical understanding about the epoch as a pessimistic symbol of downfall (for example Rostovtzeff 1926) was associated again with political events and devastation in Europe in the first half of the twentieth century (Rebenich 2009).

After World War II a changing view of Late Antiquity became increasingly popular. The work of A. H. M. Jones (Jones 1964) is seen today in a controversial and rather polemic way because of its historicism and conclusions built exclusively on written evidence and legislation of the period. Jones’ approach to Late Antiquity is called a ‘thorough conservative revision of the late Roman narrative’ (Johnson 2012, xv), a ‘suffocating vision’ (Ward-Perkins 2001a, 175). At the same time it is admitted that with his extensive knowledge of sources Jones’ survey still provides the ‘most reliable general account of the epoch’ where the decline of the Empire is explained with a number of factors (Rebenich 2009, 89). Certainly Jones’ approach was embedded in the setting of the research of his time (Gwynn 2008), and the following development of late antique studies dramatically revised it.

P. Brown (Brown 1971) developed an entirely different notion of the epoch which ‘dismissed the very idea of the decline’, claiming an extensive periodization ‘which did not leave any room for political or economic events as such’ (Marcone 2008,
This shift in historiography and in the way Late Antiquity is regarded opened new directions of research that prevail in many of the modern studies. Brown’s analysis was based on some new trends in English and French works of the mid-twentieth century which were concerned with anthropological models and cultural history. The emphasis was redirected to continuity, transformation and interaction as mechanisms of constructing the idea of Late Antiquity, rather than using disruption and crisis as leading characteristics. One of the most important contributions of this scholarship, occasionally called ‘Brownian model/ Brown’s model’, is the definite affirmation, already shaped in the historiography by this time, that Late Antiquity is a ‘quite decisive period that stands on its own’ (Bowersock et al. 1999, ix), a ‘category unto its own’ (Johnson 2012, xv) that deserves special research attention and cannot be considered simply as an intermediate moment between two great eras – Antiquity and Middle Ages.

The decades following Brown’s publication in the early seventies of the last century saw an increasing interest and growth of the studies of Late Antiquity, which consolidated as an ‘academic field in its own right’ (Mayer 2009, 12). The commonly shared modern perception is that it is ‘an intellectually, artistically, and religiously productive epoch, characterized by change, diversity, and creativity’ (Rebenich 2009, 90). Its long periodization supports the assertion that not only the post-Roman world, centred in the region of the Mediterranean, but also Iran and the Islamic Near East are part of the same processes. The overcoming of the strictly political borders shapes a historiographical trend which recognizes these developments as polycentric, with a shift in the geographical focus (Moorhead 2001; Johnson 2012). Another typical phenomenon of modern research is that Late Antiquity becomes a cross point for many academic disciplines and a complex diversity of sources and evidences is used. Despite the attempt to find a ‘single explanatory framework’ (Moorhead 2001, 248) of what happened in that epoch, regionalization is also recognised (Schmidt-Hofner 2011), leaving the impression of an intricate pattern where details are of great importance – ‘It all depends on what you are looking for, where, and when.’ (Clark 2011, 9).

Certainly, it remains for the next generations to identify and interpret the circumstances which form the directions in the modern historiography of Late Antiquity.
Antiquity in the early twenty-first century, as an approach that helps ‘to examine the discipline itself more critically’ (Rebenich 2009, 79). The increasing present-day understanding that our attempts to reconstruct past realities reflect not only the level of information and character of sources we use, but at the same time is determined by the very way we approach these sources and our attitude to these realities (Mayer 2009) is not restricted to the historiography of Late Antiquity only. Without aiming at a detailed analysis of such problems here, some points can be briefly outlined, in relation to the meaning of the present project.

Firstly, it has already been acknowledged that modern historiography does not show much interest towards certain ‘traditional’ topics such as institutional, administrative and political history (Rousseau 2009; Rebenich 2009). It is hard to conclude to what extent this is a form of reaction to Jones’ ‘suffocating’ vision of the Empire, so emotionally described by B. Ward-Perkins (Ward-Perkins 2001a, 175). However, a certain weakening of analysis of the sources is noticed (Marcone 2008) as an effect of this phenomenon. At the same time, studies within the field of economy of the epoch – a theme inevitably related to the institutions and their functions – acquire distinct forms (see Section I.3.1.), somehow detached from the analytical concepts associated with notions such as ‘uniqueness’ and ‘fascination’. Therefore, the present thesis which aims at shedding light at particular problems of distribution through analysis of a specific archaeological material may be situated within a specialised stream of research in which issues of state government and administration have to be taken into account.

Although most of the written sources signify major disruptions and crises in Late Antiquity the emphasis in the present-day research falls on the continuity linked to the previously mentioned trend of decreasing the significance of the strictly historical approaches. Criticism against such a shift in the historiography already exist (Ward-Perkins 2005 and the analysis of his work in Marcone 2008). Whether a

* ‘Late Antiquity is in essence whatever we construct of it’ (quotation in Mayer 2009, 13) – this statement mirrors one of the post-processual conceptions that, inevitably, any interpretations of the past are influenced by the present-day milieu – a wide range of our biases and consideration, not least social and political ones, emphasising in this way subjectivism and relativism as factors in the research process (Hodder 2005; Trigger 2007, 529-531, 540-548).
‘pressing need to recover a concept of ‘crisis’ in Late Antiquity’ can be proclaimed, as in the quoted publications (Marcone 2008, 17), is probably open for debates. However, the differences observed between particular regions of the Empire, the devastations, decline and abandonment attested archaeologically at almost all sites in the Lower Danube region towards the end of the 6th c. cannot be ignored (see Section I.2.1.), despite the concept of continuous transition and transformation. Accordingly, the upper chronological limit of the present research is set at the beginning of the 7th c., i.e. the moment when the Lower Danube region was eventually lost for the Empire.

It needs to be pointed out that the directions in late antique studies described above are mostly related to the history of the period. The archaeology of Late Antiquity has its own specific development, and probably ‘has been slow to emerge’ (Lavan 2003, vii) as a result of the different factors, taking into account the traditional European preference given to classical Greek and Roman culture and art since the time of the Renaissance. Nevertheless, the growing interest towards the epoch, the impact of Christian archaeology, as well as professionalization of archaeology in general supported the formation of an attentive field and academic approaches to late antique sites, layers, artefacts, etc. Nowadays, late antique archaeology is a vast area of specific research all over the world. Numerous publications appear, and the existence of specialised volumes and series confirms the richness and importance of the academic dialogue. It has to be noted though that a certain disproportion still can be seen between the nature of archaeological research in the Western and the Eastern geographical part of the late antique world (Kingsley and Decker 2001a), and this is not without consequences when more general interpretations are sought. Also acknowledged are the difficulties for Roman and late antique archaeology to fully benefit from modern trends in archaeological theory (Lavan 2003), but the ongoing development of methodologies helps to overcome this issue. It is precisely in the field of approaches and methodology where late antique archaeology has the capacity for further progress as a result of cooperation of diverse academic disciplines in modern studies on Late Antiquity in general (Mayer 2009).

Finally, a brief comment is needed regarding the perceptions towards Late Antiquity in the East European historiography. There, the development of the Eastern
Roman Empire, following the establishment of the new capital Constantinople until ca the mid-7th c. is generally seen as a historical beginning of the Byzantine political tradition and as the very origin of the Eastern Orthodox Byzantino-Slavic tradition, with all the political implications of this idea during the late 19th – early 20th c. The foundational research of East European scholars such as F. I. Uspenskii and G. Ostrogorski during the first half of the 20th c. (Uspenskii 1996-1997, originally published in 1913-1948; Ostrogorski 1940) established Byzantine studies, or Byzantinology, as a distinct area of inquiry. Without dismissal of the political crises of Late Antiquity, the ideas of a certain kind of ‘primordial’ decline and fall were by nature extrinsic to this stream of research. Consequently, the East European historiography had traditionally less incentive to disprove the concept of the ‘Fall of Rome’, unlike the strong Western perception. Furthermore, a strictly historical approach to the written sources and to evidence available from other disciplines such as epigraphy, numismatics, sigillography, and archaeology shaped the practice of late antique studies in Bulgaria during the 20th c. Some of the most comprehensive and still not entirely outdated works of V. Velkov (e.g. Velkov 1977, originally published in 1957) fostered an attentive and down-to-earth attitude towards the late antique sites and this particular field of archaeological research. Certain trends for too descriptive object-focused inquiry on the one hand, and on the other hand, of predetermined history-based interpretation of the archaeological record had (and still have) their place in the archaeology of Late Antiquity in Bulgaria. However, recent examples of a more integrated attentive approach to archaeological evidence, objective field data analysis, and evaluation of historical sources and context (e.g. Dinchev 2014) indicate the rise of a profound interpretative notion of the epoch.
I.3. Models of economy and distribution in Late Antiquity

The theoretical aspects of economy and exchange in Late Antiquity are of great importance for the present study, since the distribution networks of any kind of product are set within the general character of economy and circulation of goods as one of its particular sections. The late antique glass industry had its specifics, explained by the *modus operandi* and the character of the technological processes involved (as opposed, for example, to the ceramic production which commonly followed an undivided model of organisation). The primary production was apparently concentrated mostly close to the sources of raw materials in the Eastern Mediterranean, while the secondary working was likely linked to the places of usage of the finished objects dispersed throughout the Empire. Accordingly, this model of division implies the leading role of distribution (i.e., transportation organised in a variety of forms of supply or/and trade), a relevant high level of organisation, and at least partial commercialisation of production for the successful functioning of the entire operational chain (Whitehouse 2003). Therefore, a short outline of the main theoretical concepts regarding the late antique economic history, including commerce and exchange, is necessary as a basis for the questions addressed in the present thesis.

I.3.1. A review of the theoretical perspectives

The progress of the economic history of the Roman and late antique periods as a distinct field of academic research resembles, to a certain extent, the overall evolution of the late antique historiography (see Section I.2.2.), while it also benefits from classical economic theory and economic anthropology. The following summarised overview of the most important ideas demonstrates that the central discussion is focused on the role of the late antique state in the general economic system of the epoch.
The main debates took place between the ‘modernist’ and the ‘primitivist’/‘substantivist’ points of view (Laiou 2001-2002; Morrisson 2012a) with certain nuances, including definitions such as ‘traditional, innocently modernist approach’, ‘anti-primitivists’, ‘neo-modernists’, ‘non-minimalists’, ‘minimalistic theory’, etc. (Carrié 2012, 13-14; Kingsley and Decker 2001a, 12). Most of these positions were concerned with the theoretical models of exchange and trade, but also with the monetisation and the character of economy in general. In summary, from the ‘primitivist’ viewpoint, ancient economies, including the economy of Late Antiquity, are governed by factors which have non-economic character, but are rather political, social, and/or religious (the late antique state, army, church, etc.), and the overall level of market-type commercialisation and monetisation is low. Therefore, these economies are ‘different in kind’ from the modern one (Laiou 2002, 690), and should be studied differently. The ‘modernist’ understanding is that within the evolved complex economies such as the late Roman, at least in its commercialised sector, one of the basic determinants is identical with the mechanism of the modern economies, i.e. the impersonal self-regulating market balance of supply and demand and the profit motive. This means that the distinction between ancient and present-day market economies is ‘one of degree rather than of kind’ (Laiou 2002, 691), and approaches of modern economic theory are applicable when antiquity is studied.

Some of the leading authors of the first half of the 20th c. assumed, mostly a priori, that the Roman and late Roman economies were functioning likewise contemporary industrial market economy, and this notion influenced to a certain extent the conclusions of their studies (Rostovtzeff 1926; Pirrene 1939). Such ‘traditional, innocently modernist approach’ (Carrié 2012, 13) then met opposition from the domain of economic anthropology with so called substantivism, initiated as a theoretical tendency by K. Polanyi around the middle of the 20th c. (Polanyi 1944; Polanyi 1977). Polanyi’s construct had various aspects, not all of them undoubtedly

---

1 The opposition of opinions, summarised here without giving too detailed explanations, is relevant to the study of Late Antiquity. However, the discussion has its roots in a broader area of the previously active dispute between formal/ neoclassical economic theory (formalism) and substantivism about the binary contrast between preindustrial societies in general and contemporary Euro-American capitalism (Feinman and Garraty 2010).

2 "... a matter of degree (i.e., the quantity and complexity of information) than of kind" (Feinman and Garraty 2010, 173).
accepted (Sedlarski 2011), but the basic concept was that the profit-driven model is not applicable to early communities, where the economy is embedded in society, culture, and traditional relations. Self-sufficiency, reciprocity, in terms of gifts and counter gifts\(^*\), and re-distribution as a function of a certain kind of central authority were seen as main types of economic behaviour, leaving little space for any commercialised, market determined production and exchange. Furthermore, Polanyi defined three types of integrative patterns or mechanisms of economic allocation – reciprocity, redistribution and market exchange, and this division developed later as a ‘rigid taxonomic framing’, and a firm notion that all hierarchically organised preindustrial societies were marked by a redistributive economy as opposed to market exchange (Feinman and Garraty 2010, 174).

The positive consequence of the primitivist contribution to the discussion was a refining of the dialogue from irrelevant modernity, and also the awareness that not every example of distribution of goods is necessarily evidence for trade behaviour, i.e. commercial exchange for profit. On the other hand, that research trend coincided with the above-mentioned understanding in the historiography that the overall decline, reinforced by state domination, was a major characteristic of the late antique period (see Section I.2.2.). Hence, according to A. H. M. Jones’ analysis, the economy of the late Roman Empire was subordinate to the tax system, state organised supply of food for the army and big cities (annona), with only limited trade, and an overall non-commercial pattern of coin circulation and low monetisation (Jones 1964). M. Finley developed this opinion even further, stating a very minimalistic view about the general level of the ancient economy, as prevailing self-sufficiency, with nearly no division of labour or regional specialisation (Finley 1973). Nevertheless, his extreme assessment that the ancient society had low productivity and primitive techniques due to a lack of interest in technological innovation is definitely disproved (Greene 2000; Lavan 2007). However, the ‘Polanyian/ Finleyan’ (Carrié 2012, 13), or ‘primitivistic’ model (Kingsley and Decker 2001a, 12) was still supported in some relatively recent works (Hendy 1985; Hendy 1989) and it is present in certain academic discussions (summarised in Laiou 2001-2002; Morrisson 2012a).

\(^*\) An idea developed by Polanyi from the well-known works of M. Mauss.
The obvious strong role (but not always and necessarily leading or sole) of the late antique state in the economy through its fiscal system and army, the tight control administrated over certain productions (some extractive industries, state factories, etc.) and imperial land domains, the organisation of *annona* supplies, etc., are historical facts which cannot be ignored. Nevertheless, within such a general (or probably superficial) economic framework, exchange and distribution of goods did exist, even over long distances and in significant volumes, linked to a range of respective productions. Whether their levels should be seen as minimalistic or not, should certainly be questioned. One of the explanations regarding the mechanisms and organisation of this exchange proposed the definition ‘tied trade’ (Whittaker 1983), which in essence was developed from the opinion that political and military forces governed the economy. This concept assumed the existence of an effective distribution and commercialisation of certain productions, but bound to a setup of tax exemptions and a milieu of agents attached to big landowners, the church, or the state (as opposed to autonomous merchants operating for their own profit). In this way, the independent market-driven commercial enterprise is seen as quite limited, especially in the agricultural sector (Durliat 1998).

As it was pointed out, the traditional view of the late Roman Empire formed according to Jones’ model was drawn primarily upon historical evidences, which do not describe the entire spectrum of the economy (Lavan 2003; defined as ‘historocentric view’ – Kingsley and Decker 2001a, 3), while archaeology based reconstructions apparently shape different patterns. Thus, the accumulation of archaeological data started provoking certain changes in the academic viewpoints and formed new directions of research, ‘down into the world of economic production and exchange’, as B. Ward-Perkins figuratively asserts (Ward-Perkins 2001a, 175). Pottery, being one of the most abundant materials, provides valuable information about the mechanisms of exchange, especially in cases of well-traceable long-distance transportation of late antique amphorae and tableware. C. Wickham’ analysis of the routes of distribution of fine tableware from North Africa to Gaul and Italy proposed that the *annona* state supplies and transportation of grain can be associated with a commercialised and profit-motivated inter-regional trade of luxurious ceramics which coexisted with, but
still stayed outside of the monopoly of the fiscal system (Wickham 1988). Such ‘pick-a-back’ trade (Ward-Perkins 2001a, 173) relied on a state-run distribution network and infrastructure, and, according to some later and more extreme viewpoints, was ‘parasitic on the fiscal exchange’ (quotation after Kingsley 2001, 56). However, the same argument can be turned the other way round – ‘the state’s infrastructure vastly extended commercial penetration’ (Wickham 1998, 284). This much more liberal assessment that commercial independence did exist next to the state-institutionalised distribution highlighted the importance of archaeological data in the reconstruction of economic processes. Similar links between the grain supplies and trade of East Mediterranean late antique fine ware were also recognised, even though their mechanisms and directions seem to be more complex than the pattern observed in the Western Mediterranean (Ward-Perkins 2001a).

The advance within the field of late antique amphorae research demonstrated the existence of comparable tendencies in the supply of wine and olive oil – the two main marketable agricultural products of the Mediterranean (for example Kingsley 2001, Decker 2001, Karagiorgou 2001, Karagiorgou 2009, Pieri 2012). The particular focus on the development and spatial distribution of amphora types gradually shifted the discussion away from the general questions about the character of late antique economy as a whole, to problems of exchange as one of its most dynamic layers. Identification of the origin of certain amphora types and tracing the areas of their spread demonstrated that the distribution networks were quite wide and complex, and that in certain cases they resisted political events and went across political frontiers. The overseas and regional routes were obviously intertwined, and such networks are certainly not explainable only as state-organised wine and oil provisioning or as limited commercial distribution associated with the directions of state supplies (Ward-Perkins 2001a). Without doubt, trade for profit existed as an economic phenomenon of significant scale, even though not particularly well-documented in the official historical sources; the amphorae trade, which is easily traceable in the archaeological record, was only one section of it (Mundell Mango 2001). These considerations gave reason for stating the notion of an ‘open economy’ regarding Late Antiquity, in an attempt to revise the minimalistic interpretations which
dominated the scholarship so far (Kingsley and Decker 2001a, 12).

The present-day research demonstrates an intention for a balanced view of pre-modern economies and conscious efforts to overcome the ‘false primitivist-modernist dichotomy’, because such ‘categorical thinking’ has been ‘proven to be analytically unproductive’ (Feinman and Garraty 2010, 176). Regarding Late Antiquity, ‘the picture of conflict between state-led and private/commercial diffusion of goods’ does not seem plausible (Ward-Perkins 2001a, 174) but was formed apparently as an unwitting projection of particular contemporary notions. Different categories of late antique evidence points to the existence of a market-type economy and demand-supply mechanisms, while the specific fields of the state’s economic activity apparently did not interfere with the commercial life in the Empire. On the contrary, the late antique state and church acted at some point as the largest private entrepreneurs (Carrié 2012), and a certain amalgamation of public and private interests was quite probable (Schmidt-Hofner 2011). The high level of monetisation is undeniable, even though this cannot be seen by itself as evidence for market phenomena, but mostly as an integrating element. At the same time, the definition of the late Roman economy as a ‘conglomeration of independent markets’, ‘a network of interconnected but relatively ‘free’ markets’ (Morrisson 2012a, 2) does not downplay the significance of other forms of non-market interactions – reciprocal and redistributive, following the terminology of Polanyi’s model. Thus, for the present-day research and from a methodological point of view, it is crucial to recognize correctly these different types of behaviour as reflected in the written sources or the archaeological record – i.e. ‘non-economic exchange’ and ‘commercial exchange’ (Laiou 2002, 683). In other words, ‘not to confuse trade and distribution’ (Laiou 2002, 692)”, i.e. commercialised exchange for profit and transportation of state-led food supplies, circulation of goods within the same big landlord’s properties and estates, etc.

The increasing amount of available archaeological data, numismatic information, analysis of written sources, and not least the use of multidisciplinary

* It should be stressed, however, that the definitions given by A. Laiou (Laiou 2002) are not consistent, and a certain confusion may be noted when ‘non-economic exchange’ is used as a label for non-commercial distribution, although it is still a particular section within the economy as a whole.
approaches allow to delineate the complex and dynamic character of the economy during Late Antiquity. Nevertheless, reconstructing its complete image is a research process which would include putting together reliable facts and interpretations, and at the same time not forgetting that some parts would remain less clarified, or even blank.

A very schematic outline of the economic system in general consists of production and distribution/trade, which function in the broader context of consumption, services, transport, administration, development of technology, and many other socio-cultural factors. The basis of the late antique economy, as for all pre-modern societies, was the agricultural production, with all relevant aspects of its diversification and regional specialisation in crop and stock rising. Above the levels of subsistence and obviously needed self-sufficiency, the agrarian sector of the economy could produce a surplus, which had effect as taxes in kind, or it was traded to closest urban centres of consumption, but also could be strategically developed into specialised and commercialised extensive mono-cultural production (for example wine, olive oil), targeting different levels of demand.

Regarding the non-agricultural sector of the economy, it can be argued that a variety of extractive and primary processing industries had a fundamental role, as suppliers of raw materials for diverse artisanal activities and craft manufactures. Unlike agriculture, the procurement and exploitation of mineral resources would require a relevant degree of professionalization and management. At the same time, the specialised nature of most craft productions implies at least some commercialisation, even though it was a quite wide spectrum between domestic crafts at the level of self-sufficiency up to luxurious and/or far-flung traded commodities.

Trade and transactions of goods were probably the most dynamic section of the late antique economy which had an essential role in the overall development, processes of integration and urbanisation, exchange of information, etc. (Morrisson 2012a, Laiou 2002). The distribution of certain indicative groups of archaeological material allows the routes and mechanisms of commerce and distribution to be traced, and this became the focus of an active academic interest (for example volumes such as
Hodges and Bowden 1998; Kingsley and Decker 2001b; Mundell Mango 2009b; Morrisson 2012b, and many other works, as shown above). The intensity of the debates may leave the impression that such a discussion and its outcomes covered nearly the entire research field of late antique economy. However, many aspects still remain elusive. Firstly, trade is not synonymous to the economic system as a whole. Furthermore, certain subsections of trade were defined as ‘elitist and marginal to the general economy’ (Mundell Mango 2009a, 6). Certain other categories of goods, because of their nature (perishable packing, loose cargo, etc.), have left hardly any trace in the archaeological record (Morrisson 2012a). For example, the distribution of spices and textiles can theoretically fit the model of the late antique commercialised production and market exchange. However, evidence of such kind of trade is archaeologically too elusive. At the same time, it is worth noting that other, definitely not marginal materials typically are left outside the debate. The supply of metals such as iron, which had basic practical use in all spheres of production, needs also to be taken into account, and probably a different and more complex picture would emerge, knowing the strong involvement of the late antique state in metal industries.

As already pointed out, when the late antique trade and distribution are studied, it is especially important to identify the mechanisms which underlie the movement of goods – non-commercial grounds based on reciprocity and/or re-distribution, or profit motive based on market-type supply – demand force. Another kind of structuring can be developed according to the levels, or spatial scale of circulation of commodities. The division into local, regional and inter-regional levels (Morrisson 2012a) reflects a very significant difference between distribution networks, namely different levels of production and targeted levels of consumption/demand and markets. The observation of a market economy as a set of numerous markets is rooted exactly in this reasoning, and the processes of exchange of goods should be seen as ‘chains of transactions on various tiers’ (Morrisson 2012a, 4). An agreement exists that it was not the inter-regional trade, or long-distance distribution that indicated the degree of economic vitality, but that the development of regional networks was the true measure for prosperity or decline (Wickham 1998, Ward-Perkins 2001a,
Morrisson 2012a). The exchange on a local level, on the other hand, can be associated with a more autarkic mode of economic functioning.

The different mechanisms and levels of exchange and distribution did not form a static pattern, but instead a variety of dynamic interactions and stages of redistribution can be recognized (Laiou 2002). An olive oil amphora can start its ‘journey’ as part of *anonna militaris* state-run supplies on an inter-regional level, but then may enter the regional monetised network of market trade as a piece in a smaller consignment, and finally be re-used just as a single container for any other kind of liquid on the level of local exchange. Such an extreme and theoretical example would help to illustrate that there is much to be inferred from the interpretation of the archaeological record. Acknowledging how complex the evolved late antique system of production and distribution was, the modern approach to its study strives to determine, characterise, and possibly, to quantify different elements, to understand the dominating factors in their regional and chronological variations, so as to shape a fuller picture of the general economic life.

I.3.2. Glass studies in the context of the debates on late antique economy

The review presented above suggests that only a thorough research on a wide variety of sources would make it possible to construct a persuasive image of the late antique economy. Historical sources and archaeological data help to unravel its different sections and aspects, and may complement each other, instead of being contrasted. Amongst the diversity of archaeological materials, pottery seems to be the most often studied evidence of exchange. Glass production and circulation are also mentioned (probably the most reasonable, even if only brief discussion is in Carrié 2012, 17-18; some not quite up to date comments in Ward-Perkins 2001a and Kingsley 2001; a broader summary on Byzantine glass production is in Laiou and Morrisson 2007), even though the recent advance in glass studies, especially compositional analyses provides a much larger basis for conclusions. Unavoidably, a certain lack of correspondence becomes evident between the enquiries focussed on the chemistry and archaeology of
late antique glass, and those concerned with the broader interpretations of economy of the period.

1.3.2.1. The current stage of research

Glass studies which explore finds dated to the Roman period and Late Antiquity represent a well-established scholarly field, with a history of already more than one hundred years (cf. Morin-Jean 1913). In accordance with the conventional approaches in archaeology, a considerable interest in classification and date of vessel shapes generated a range of chrono-typological works. The fundamental publication of C. Isings (1957) became the commonly accepted and standard nomenclature of the vessel forms from the 1st – 4th c. Other studies strived to combine the strictly morphological approaches with attention to glass colour and manufacturing techniques (e.g. Harden 1936; Hayes 1975). The accumulation of archaeological glass finds from excavated site assemblages and museum acquisitions with more limited information of object provenance gave rise to a growing range of volumes and papers which discuss a wide spectrum of research topics: catalogues of leading museum collections (e.g. Whitehouse 1997-2001-2003) or exhibitions (e.g. Harden et al. 1987), overviews of particular technological groups of glass vessels (e.g. Meredith 2015; Stern 1995), regional studies (e.g. Price and Cottam 1998), presentations of glass from defined chronological periods (e.g. Laflı 2009), site vessel assemblages (e.g. Weinberg and Stern 2009), finds from production contexts (e.g. Antonaras 2014), and many others. Inquiries regarding the chronology, technology of manufacture, places of origin and areas of distribution of glass vessels, morpho-typological developments, etc. form some of the main trends in the present-day archaeological glass research.

In parallel to this, considerable progress of the analytical research on Roman and late antique glass compositions was mostly facilitated by the technological advance of the laboratory methods, and the growth of archaeometry as an academic discipline. The primary interest regarding the raw materials used in ancient glassmaking allowed the main chemical categories to be defined (e.g. Sayre and Smith 1961) and the technologies of production to be discussed (e.g. Henderson 1985). A significant advancement in the multidisciplinary research on Roman and late antique
glass was driven by the ‘the concept of a division of production’ (Freestone 2006, 202), i.e. the reconstruction of the glass industry of those periods as organised in two distinct stages – primary production of raw glass and secondary manufacture of finished objects (Nenna et al. 1997; Foy and Nenna 2001; Freestone et al. 2000; Freestone et al. 2002a; Freestone 2005). Although not always undoubtedly accepted (cf. Wedepohl and Baumann 2000; Wedepohl et al. 2003), this theoretical framework remains the leading one. More recently addressed also as ‘dispersed versus centralized’ model of glass production (Jackson 2005, 765), or ‘localised versus regional’ (Foster and Jackson 2009, 190), the scientific discussion about the functional mode of the Roman and late antique glass industry seems focused to a great extent at geology and origin of the raw materials. The possibility to unequivocally identify certain compositional groups at the sites of their production (e.g. Levantine I glass – Freestone et al. 2008b), or, based on distinct geological settings, to point to wider regions as potential places of origin of other groups (e.g. HIMT glass – Freestone et al. 2005; Nenna 2014) allows tracing the provenance of glass found in various contexts in the Mediterranean and beyond. Furthermore, the increased application of various analytical techniques (cf. Janssens 2013) enables addressing a wide spectrum of technological questions such as characteristics of the sand sources (Degryse 2014), glass recycling (e.g. Jackson 1996; Freestone 2015), colouring (e.g. Cagno et al. 2014), contamination (Paynter 2008), etc.

Remarkably, it seems that glass studies often face difficulties to integrate the archaeological and archaeometric evidence, and to successfully interpret both kinds of information simultaneously. A possible reason for a conclusion that these two aspects have no relation to each other (e.g. Gallo et al. 2014) could be found in the stronger attention to purely formal vessel morpho-typology than to the style of manufacture and finishing of the objects. Nevertheless, fundamental research on late antique glass (e.g. Foy et al. 2003) demonstrates that successful integration of these two kinds of analyses is not just possible but quite beneficial for the final interpretation of the finds.

As demonstrated above, the archaeological aspect and the chemical compositions of Roman and late antique glass are intensively examined in numerous publications, but their further detailed overview is beyond the scope of this project.
However, a summary of the current state of work on materials from Bulgaria is necessary in order to situate the present study within the developments of this particular research area.

Several archaeological publications discuss glass vessel assemblages from Roman and late antique sites in the Lower Danube region (e.g. Minčev 1988; Minčev 1992; Olczak 1995; Shepherd 1999; Gomolka 1979; Gomolka-Fuchs 2007; Băjenaru and Băltăc 2000-2001), and they form a significant basis for typological comparisons, and partially, for reliable chronological conclusions. The analytical work on chemical composition of the glass vessels and production waste from Novae provides certain information as well (Olczak 1998). However, this volume probably demonstrates, from a present-day viewpoint, a certain incompleteness of the general interpretation due to the state of understanding of glass chemistry at that time (similar in Dekówna 1985 and even more recently in Shchapova 1998; Stawiarska 2014; Dekówna and Dymaczewska 2014). Some other publications of compositional data obtained from sets of various Roman and late antique glass finds from Bulgaria also may not meet the currently expected level of interpretation of the results due to general methodological issues (Kuleff and Djingova 1999; Kuleff and Djingova 2002). Nevertheless, a few more recent works (e.g. Lesigyarski et al. 2012) demonstrate awareness of the currently accepted model of division of the Roman and late antique glass production and its implications for the understanding of compositional data. Attempts are made also to better comprehend the significance of various analytical techniques in glass studies (e.g. Zlateva and Kuleff 2015).

It should be pointed out that the application of modern and appropriate analytical methods such as EPMA or LA-ICP-MS (see Section II.2.1.) on archaeological glass from Bulgaria remains limited, although these laboratory approaches can provide better and more complete insight into glass chemistry, and hence allow its better reading. One of the expected impacts of the present project is to expand the existing reliable analytical database, and therefore, to contribute to filling this lacuna in the current level of research in Bulgaria. Another positive effect of this work, again mostly in the methodological setting, would be the integration of archaeological and scientific approaches, since this brief review of the publications on Roman and late antique glass
from Bulgaria demonstrates the existing disconnection between these two areas of studies. Moreover, relating the discussion of late antique glass with the debate about distribution and economy sheds light on the significance of glass research for the construction of broader socio-cultural narratives.

I.3.2.2. Methodological and interpretative potential of glass studies

Several main characteristics of glass and glass vessels have to be spelled out when this particular category of archaeological material is regarded within the context of the research on late antique economy:

- Firstly, due to their wide usage, glass vessels represent a more or less abundant archaeological mass material on most late antique sites in the Balkans and beyond. In this way, these finds provide, like pottery, a large and quantitatively representative database. At the same time, unlike pottery and similarly to metals, glass almost always undergoes recycling (as part of the routine practices of re-melting and re-use). Hence, glass is more complex in terms of the interpretation of quantities of finds, compositional data and distributional patterns.

- There are no firm and direct indications in written sources from the period about the organisation of glass production and trade. Raw glass cannot be seen as a basic commodity of strategic importance for the state (like grain, silver, iron, etc.), and even in the everyday life glass objects were probably among the ‘wants, not needs’ (Mundell Mango 2009a, 6). Therefore, glass can hardly be directly related to the state governed section of economy. At the same time, the majority of this production, especially the large-scale primary glass melting, was definitely of industrial size and, therefore, it could not belong to luxurious neither to marginal productions within the general structure of economy.

- The chemical composition of glass contains specific evidence of the geological nature of raw materials used, the recipes for its primary production and indications for further secondary modifications (see Section II.1.1.). Accordingly, glass is a very suitable material for provenance studies, tentative identifications of supply routes and their dynamics, as well as of various levels of economic connectivity or isolation.
- Through investigating particular features of glass vessels as finished artefacts (as opposed to the raw unworked glass), such as morpho-typology, the style of manufacture and decoration, etc., another area of interest can be addressed, shedding light on the existence of stratified distribution networks of secondary glass production, and related to it stratified consumer’ demands as an economic and socio-cultural phenomenon.

- Finally, certain particular approaches in glass studies, such as ‘single batch’ evaluation (see Section II.1.2.) allow very detailed interpretations about the mechanisms of acquisition of glass vessels, and hence provide a unique opportunity to hypothesise diverse mechanisms of distribution in the overall context of the economy.

Taking into account these distinct characteristics of glass as archaeological material, it is believed that the present thesis makes a methodological and interpretative contribution to successfully clarify certain particular aspects of the economy of Late Antiquity. Specifically, an integrated analysis of vessel glass assemblages designed according to the explanatory model of distribution networks provides insights into:

1. Long-distance and interregional transportation of high volume/low value goods, i.e. the far-flung networks for distribution of primary raw glass. Such shipments, due to their specifics (almost entirely re-worked in the secondary glass workshops, no archaeologically preserved traces of their packing) can be traced mainly by compositional analyses of regionally/locally produced finished objects.

2. Interaction and blurring between interregional and regional/local networks of distribution and related consumption, and dynamics of these processes. The very nature of late antique glass production suggests such an interaction since the raw glass supplied over long-distances was meant to enter the smaller levels of subsequent re-distribution within the regions with marginal geographical positions.

3. Non-commercial distribution networks as part of the economic connectivity in general, but quite different from the state-led re-distribution of staple foodstuff. As already pointed out, most of the late antique glass vessels are not luxurious items.
However, within site glass assemblages certain specific examples may be recognised as indications of the status of their owners, as one-off acquisitions that likely marked social phenomena (hierarchies and reciprocity), objects with particular religious significance, etc. Such finds can shed light on distribution driven by non-commercial mechanisms which also formed part of the overall exchange system of the period.

The introductory Chapter I outlines the main objective of the thesis as characterisation of the glass distribution in the Lower Danube region through integration of conventional archaeological artefact study and scientific analysis. The research is based predominantly on vessel glass finds dated to the late 3rd – early 7th c. found at three sites in present-day Bulgaria. The interpretative model of distribution networks includes discussion of their spatial differentiation (inter-regional, regional, and local networks), as well as recognition of the socio-economic mechanisms of their functioning (market-type trade, commercialised tied exchange, non-commercial distribution). Such an approach is aimed at better understanding of the dynamics of the glass circulation and usage, and at reconstruction of the way in which these vessels were positioned in the economic system and the broader social notions of the population at the margins of the Empire.
The previous Chapter I presented the main objective and the research questions of the thesis, while the sections of Chapter II address the problems of methodology and particular approaches applied for the accomplishment of these goals. In this respect, achieving an effective integration of archaeological evidence of production, supply, and usage of glass vessels in the Lower Danube region and on the other hand the scientific data regarding chemical composition of the finds has a decisive significance. A classification based on integrated technological criteria, i.e. both the technology of glass production and the technology of vessel manufacture is the preferred choice here, corresponding to the first research question, i.e. how should the dataset of primary evidence be organised. The present Chapter II discusses the methodological aspects of such a classification, followed by a presentation and evaluation of analytical techniques of the research.
II.1. Methodology of an integrated classification

Archaeological as well as archaeometric data can be arranged in a variety of ways, according to the particular aims sought. Simple sorting according to straightforward criteria (e.g. object sizes, concentrations of a single compositional variable) as well as more complex constructs (e.g. object morpho-typologies, extensive compositional grouping) would be equally possible but serve different goals. Interestingly, the theoretical aspect of archaeological classification has received much attention in the literature (cf. Klein 1991; Adams and Adams 1991; Gardin 1980), while the underlying principles of compositional grouping of late antique glass are not clearly defined. In most of the cases such grouping is a priori assumed to be provenance-oriented. Nevertheless, some researchers tend to distinguish between geochemical and technological criteria for classification of compositional glass groups (Foy et al. 2003, 79). The objectives of the present project outlined in Chapter I require an integration of the archaeological and archaeometric evidence into a general interpretative construct. Such a construct/classification is aimed at revealing a meaningful data pattern, which would ideally help to identify ‘the relationships tying human beings to material objects’ (Lemonnier 2012, 19) on the basis of the explanatory model of distribution networks.

Certain cases in the literature on chemical glass compositions of Late Antiquity claim the use of a ‘combined approach involving both chemical and archaeological data’ (Gallo et al. 2014, 18). At the same time, the archaeological data is by definition limited to vessel morpho-typology only. The methodology applied in this study follows a different direction, and is informed by the theoretical views regarding the role of technology for past social identities and systems of thoughts.

The following paragraphs outline the specifics of compositional data ‘reading’ and interpretation, associated with an understanding of the diverse factors that have
an effect on it. Furthermore, the methodological approaches to classification built on integrated technological criteria are discussed.

II.1.1. Chemical glass composition as evidence in an archaeological enquiry

Structurally, archaeological glass may be described as an artificially produced non-crystalline solid material (amorphous solid) which throughout history is silica-based and can have a variety of chemical compositions (Artioli 2010). The glass commonly produced within the territories of the Roman and Early Byzantine Empire is of so called low-magnesia soda-lime-silica composition (\(\text{Na}_2\text{O}–\text{CaO}–\text{SiO}_2\)), likely made from two main ingredients – silica sand, containing lime (from shells or limestone), and evaporitic mineral soda, also termed natron (Brill 1988; Freestone 2006). The model of two-stage organisation (see Section I.3.2.1.) suggests that the primary glass melting was associated with a few particular industrial sites which required basic supplies of natron, sand, and fuel (and probably access to suitable clays for furnace building and water resources as well).

The origin of soda is approximately established – apparently, one of its main sources for procurement and export during the Roman and late antique periods was situated in Egypt (cf. Shortland et al. 2006; Freestone 2008; Devulder and Degryse 2014). The sands used in the glass making of that time most probably came from various coastal beach deposits in the Mediterranean (cf. Degryse 2014), and large scale furnaces for primary glass production, attested so far in Egypt and Syro-Palestine, were found in their vicinities (e.g. Freestone et al. 2008b; Nenna 2008).

Admittedly, mineral soda is a relatively pure raw material with more-or-less constant chemical composition which was likely used at all of these production sites. On the other hand, sand is formed mostly of quartz, that is silica, but it also contains different mineral impurities. Basically, they vary according to the characteristics of the source rocks and possible subsequent changes introduced by fluvial and coastal transport, which can remove certain minerals through weathering and sorting, and add others from secondary sources of other eroded materials. These impurities can be
present in higher concentrations, or just as minimal inclusions. Their specific levels and combinations (‘sand markers’ – Rehren et al. 2010, 68; ‘chemical signature/ fingerprint’ – Degryse 2014, 23) are reproduced in glass compositions as co-variations of certain compounds. Major and minor oxides (i.e. the oxides in concentrations >1 wt% and between 1 and 0.1 wt%, respectively) such as alumina, lime, potash, magnesia, iron oxide, phosphate, titania, etc. in glass reflect the characteristics of the glass making sand. Similar significance, on the level of trace oxides (in concentrations <0.1 wt%), have ZrO$_2$, Cr$_2$O$_3$, La$_2$O$_3$, Y$_2$O$_3$, etc. (cf. Brems and Degryse 2014). Therefore, the geochemistry of sand, as a result of particular geological settings has a diagnostic importance for the recognition of different glass compositional groups, respectively of different primary production locations, and hence it provides the basis for provenance studies.

At the same time, chemical glass composition is an indication not only of a specific sand geology, but also of the recipes for glass melting used by ancient producers. The levels of sand-deriving oxides in glass replicate particular geological features in the raw material and could not be deliberately adjusted by the craftsmen. However, the content of other compounds depends on certain decision of the producers, since these compounds were intentionally used as part of the recipe, technological tradition and choices, availability of raw materials etc. The concentrations of soda, for instance, are considered to be determined mostly by the recipe (Foy et al. 2003). Other compounds, which are not essential part of the base composition but have the function of additives, are aimed to change the appearance of glass – manganese and antimony oxide mostly served as decolourisers (Jackson 2005), while some metal oxides, such as those of copper, cobalt, and iron give strong colours (blue, green, black, etc.). In some cases, relatively pure geological or artificial materials are used as additives in glass (e.g. pure iron oxide in the form of hammer scale, micro-slag formed as a by-product of iron-smithing – Rehren et al. 2012; Cholakova and Rehren 2014). However, certain other minerals used as additives represent various associations of compounds, and in this way they introduce an additional ‘layer’ of impurities in the glass composition (e.g. traces of strontium oxide introduced by manganese containing mineral – Cholakova et al. 2015).
Furthermore, the interpretation of glass chemistry is not straightforward, since various other factors have effects on it. During the primary melting, or secondary re-melting, for example, the batch is often contaminated by the fuel used in the furnace, which may increase the levels of potash, magnesia, and/or phosphate (Paynter 2008, Tal et al. 2008). Recycling glass cullet, glass blowing waste, or mosaic glass tesseræ, which was a common practice during the Roman period and Late Antiquity inevitably causes mixing and blurring of glass compositions (cf. Freestone 2015; Jackson and Paynter 2015). In some cases re-melting of pre-existing glass could lead to a slightly elevated content of certain additives, i.e. colorants or decolourisers which may indicate indiscriminate recycling of diverse glasses (Jackson 1996), or unintentional addition of fragments with coloured decoration to the batch. Contamination of glass with additional iron oxide or alumina may also be possible at the stage of the secondary working as an effect of the prolonged contact with ceramic crucible/furnace material and glass blowing tools. At the same time, the concentrations of some of the recycling indicators in glass remain generally low, and very similar levels could come from the sand geology as well, if sand with higher amounts of mineral impurities was used. Finally, the evaporation loss of soda should also be mentioned as a likely effect of prolonged heating and repeated recycling.

Summarising, the chemical composition of glass has complex characteristics that shed light not only at the geochemical patterns and origin of the glass making sands used, but also on various technological features of primary glass production and secondary re-working. Remarkably, these phenomena may overlap in the final chemical glass makeup, i.e. similar levels of a single oxide in different cases may reflect more than just a single explanatory parameter (e.g. a higher amount of apatite as a sand impurity and fly ash contamination during re-melting could result in identical $P_2O_5$ concentrations – cf. Rehren et al. 2010). Therefore, a thorough understanding and interpretation are necessary in order to unravel all aspects of the studied glass compositions.

The present research is an attempt to consider the compositional data as archaeologically significant evidence which, likewise the archaeological record, is formed by various processes, and hence should not be seen simply as a mass of fixed
and set patterns. Modern analytical techniques offer a unique opportunity to ‘unfold the histories’ of particular chemical glass makeups∗, with all the specifics of the primary melting and subsequent modifications. The main implication of this reasoning is that these modifications, seen in a retrospective way from the last re-melting to the initial moment of production, or indeed the lack of such modifications represent evidence of technological choices which are indicative of wider economic and socio-cultural practices.

II.1.2. Integrated classification and technological style/ chaîne opératoire approach

The starting research question of this study is concerned with the organisation of the primary archaeological and archaeometric evidence that would allow to identity interpretable patterns related to distribution networks (Section I.1.). Therefore, a significant part of the thesis is engaged in constructing an integrated archaeological and scientific classification of the material. The chosen way to address the variability within the current dataset, both in terms of vessel artefact characteristics and chemical glass compositions, is rooted in technology, recognised as ‘a system of behaviours and techniques, guided by human choices between several alternative approaches’ (Stark 1998).

The theoretical concept of technological style or chaîne opératoire as a framework for understanding the socio-cultural significance of technology is widely used in present-day archaeological research (cf. Martinón-Torres and Killick 2015). However, its potential for glass studies of Late Antiquity may still be underestimated. Without putting too strong emphasis on the theoretical arguments, two main reasons justified the application of this approach in the present project. First of all, being more than simply a method for reconstruction of production sequences, the chaîne opératoire research is commonly acknowledged as a powerful medium to look at the past socio-cultural identities and broader phenomena behind the technology (cf.

∗ An understanding which is remotely influenced by archaeological theory approaches of ‘artefact biographies’ and ‘social history of things’ (cf. Appadurai 1986, Kopitoff 1986). Similarly to ‘the shifting roles and meanings of an artefact over time and context’ (Mytum 2003/2004, 112), the compositional modification of glass can inform about certain technological choices and their economic environment.
Dobres 1999, Dobres 2000; Schlanger 2005). Accordingly, this is in agreement with the objectives of the project to extent the interpretative meaning of the archaeological and archaeometic data, through reconstruction of distribution networks, and into a narrative of the socio-economic dynamics within the Lower Danube region in Late Antiquity.

Secondly, a classification based on complex and even versatile criteria, which assume that both technology of glass production and technology of vessel manufacture have a leading interpretative meaning can shift the main focus of the enquiry. Instead of aimed only at building a complete outline of vessel shape typology, or, only at the identification of primary glass production locations, such a classification is concerned mostly with an integrated, ‘chaîne opératoire’-built insight into the details of a given glass making recipe and its subsequent modifications, and the details of vessel finishing. This solution has numerous advantages in view of the two main limitations of the divided archaeological and archaeometric approaches. Firstly, the overwhelming majority of the studied glass vessels are preserved only in fragments, and entire reconstructions of their shapes are often not possible. Secondly, the compositional results allow certain chemical glass groups to be related to particular production locations or regions in the East Mediterranean, but in other cases such geographical identifications remain rather uncertain.

The process of construction of this integrated classification involves several stages of analysis. Regardless of certain variations in their implementation due to particular specifics of the studied assemblages, the general line of reasoning is as follows. An initial grouping of the materials is based on archaeological criteria, where the characteristics of object manufacture and essential features of vessel finishing have a leading importance – e.g. diversity of glass blowing techniques, cold-worked or fire-rounded rim finishing, use of pontil and removal of the pontil scar, various ways of decorative thread application, etc. The application of these techniques is not random but is rooted in particular craft traditions and hence, they are seen as useful discriminants for delineation of different levels of vessel glass manufacture. At the same time, the formal object morphology, vessel type, decorative styles and schemes are largely influenced by other more general factors, such as their utilitarian function,
wider aesthetic preferences, exchange of decorative models and spread of particular fashions (Fig. II.1.). Therefore, they are considered as less indicative criteria, and moreover, not always applicable when only small fragments are preserved. However, this classification, even if it has a more complex nature, does not exclude the strictly typological method in cases when meaningful identifications are possible. The colour of the glass as part of the initial visual assessment of the fragments is also taken into account, similarly to the approaches used in earlier studies (e.g. Hayes 1975).

The next step of the research consists of the selection of fragments for laboratory analysis, followed by tracing the initially outlined archaeological groups against the obtained compositional data. This addresses the question about the relationship between archaeological characteristics of the objects and the glass fabric (cf. Freestone et al. 2002a, 258). Chemical data which shed light on the aspects of glass-making recipes and modifications (e.g. use of additives as glass colour modifiers, evidence of recycling, etc.) are discussed with particular attention since they reflect choices of the craftsmen and broader technological practices of the period. At the same time, the geochemical characteristics which point to the origin of the glass groups are also considered, and affiliations to known compositional groups are made.
At this point, these methodological notes seem to divide the research into archaeological and scientific stages. This may be a reasonable technical separation, admitting that analysing the entire glass assemblages is not possible, and the logic of sample selection can only be based on an initial visual assessment of the finds. However, the intention for an integrated classification of the materials would mean that its construction is more than a ‘one direction straight line’ from archaeology to chemistry of glass. The successful process of revealing the meaningful pattern of groups within the assemblages requires a continuous comparison and iterated adjustment between archaeological and compositional data (as described by French scholars – *va-et-vient* way of research, Foy *et al.* 2003, 80). The benefits of this repeated comparison of both aspects of the finds are most evident when outliers or samples with intermediate position are identified and explained, or in cases when the attribution of a certain subgroup to a bigger group is discussed.

In this way, the outlined classification of groups in the present study has an open structure, both in terms of addition of new groups or separation of subgroups. The outcomes of the integration of archaeological and compositional evidence may be even seen as too ‘flexible’ if compared to strictly archaeological classifications, or to detailed statistical grouping of chemical data. Nevertheless, the present study takes this classification as a tool (as opposed to its goal) for identifying the various levels and types of distribution networks. Acknowledging that these networks certainly had a dynamic nature and were often merging, more versatile criteria of the classification are justifiable.

A few more methodological aspects should be also spelled out in the present section. A comparative approach to all the results in regard to other similar glass assemblages and published data (both archaeological and compositional) is necessary when glass vessel finds from the Balkans are discussed and interpreted within the general picture of glass production and distribution during Late Antiquity. Furthermore, the ‘single batch’ evaluation should be mentioned as well as part of the approaches for revealing the significance of analytical results in their archaeological context (Price *et al.* 2005; Freestone *et al.* 2009). Integration of chemical data and analysis of vessel morphology allows inferring the mechanisms of procurements and acquisition of the
artefacts to the site, (i.e. vessels manufactured from one and the same glass melt, as part of the same episode of production, and delivered to the site as one-off acquisition). Such an approach contributes to a detailed and nuanced interpretation of the finds and has a particular significance when occasional non-commercial distribution of finished vessels is traced.

Finally, it has to be admitted that despite the intention for an objective primary data processing and classification, two aspects of the interpretation of the outlined groups remain relatively debatable. The first aspect is linked to the assessment of workmanship, i.e. the quality of the vessels as finished objects. Although some of the finds are obviously high quality luxurious items, it is not easy to define strict criteria for distinguishing between low-quality ordinary production and more elaborate glassware. Some indications can be found in vessel decoration, thickness of the walls, the tool marks and overall shaping of the silhouette. However, the assessment of high- and low-quality, respectively high- and low-value is relative to certain more complex past socio-cultural measures and customers’ habits which cannot be fully reconstructed. The other aspect which is difficult to define objectively is related to quantification, i.e. the frequency of distribution of particular groups, or the degree of their commonness within the Lower Danube region. The studied site assemblages provide a good basis for tentative conclusions about the extent of popularity of certain vessels, and respectively, about the likelihood of their regional production based on distribution patterns. However, future discoveries or detailed study of other site collections may change these conclusions, given that the overall state of research on late antique glass from Bulgaria is not too advanced. Nevertheless, despite these limitations the present study addresses questions of quality and frequency of distribution of the identified glass groups since they are of great importance for understanding the nature and geographical dimensions of the distribution networks.
II.2. Analytical techniques and approaches

This section provides an overview of the analytical techniques applied for the compositional characterisation of the samples in the present study, as well as a summarised discussion of the statistical approaches to the data. The particular analytical procedures and runs are outlined, followed by a critical assessment of the quality of the obtained results. The compatibility of the EPMA and the LA-ICP-MS datasets is discussed in detail, certain problems are recognised and their appropriate solutions are presented. The aim of this thorough data evaluation and refinement is to ensure that further conclusions and interpretations of the glass finds are based on consistent and reliable primary compositional evidence.

II.2.1. Laboratory based techniques

Ancient glass is studied using an increasingly wide range of methods and instruments within the overall growing field of interdisciplinary research in archaeological materials (a review of the most commonly used methods is given in Janssens 2013). Many of these techniques determine the chemical glass composition, whereas others are applied when microstructure, isotope signatures, oxidation state, etc. are of interest. A detailed overview of such an array of tools is beyond the scope of the current discussion, since the project’s main questions can be successfully addressed through compositional analysis of glass. Electron probe microanalysis (EPMA) and laser ablation inductively coupled plasma mass spectrometry analysis (LA-ICP-MS) are the two techniques applied in this study for the measurement of major, minor, and trace oxide concentrations in glass.

II.2.1.1. Basic principles of the analytical techniques

A summarised overview of the basic principles of EPMA and LA-ICP-MS techniques provides the necessary background for further comments and comparisons
of the advantages and the limitation of each analytical method, and their practical implications for the current research.

The EPMA technique belongs to the broad range of X-ray based methods for chemical analysis (Pollard et al. 2007). The underlying principle of compositional characterisation is based on the following: when the surface of the sample is affected by the instrumental beam of accelerated electrons certain changes in the positions of electrons within the orbital structure of the atoms in the sample, result in the emission of X-rays at particular wavelengths, specific to each element. The chemical composition is determined by detection and measurement of these characteristic X-rays which correspond to the elements present in the sample. Different varieties of the setup configurations are in use, and the EPMA instrument is distinguished by the application of wavelength dispersive X-ray spectrometers (WDS), as opposed to the more common but less sensitive energy-dispersive spectrometers (EDS). This method of detection of the X-rays emitted from the sample is based on a specific diffraction system. The advantages of the WDS technique, compared to some other X-ray methods, include its higher primary beam intensity and stability, and a better sensitivity and peak resolution of the spectrometer, resulting in an overall more accurate quantification. Admittedly, much more complex mechanisms of the EPMA functioning are involved, compared to the general outline presented here. However, from a practical point of view, it is important that the EPMA analysis offers a non-destructive (but still invasive, i.e. sampling is a requirement for analysing non-corroded areas of glass fragments, but the integrity of the samples themselves is preserved), reliable and established technique for glass composition characterisation. The limits of detection are sufficiently low to determine, besides the major oxides and at least most of the minor oxides (i.e. oxides present in concentrations between 0.1 wt% and 1.0 wt%), also certain trace oxides (<0.1 wt%). At the same time, problems such as the time consuming sample preparation, the direct link between the quality of its performance and the quality of the obtained compositional data due to the complex geometry of the setup, matrix effects (analytical interferences between different compounds in the glass), etc. should be mentioned as well. The ability of the EPMA technique to reliably quantify oxides in the major range and most of the oxides in the
minor range is well recognised. An accurate quantification below the level of 0.1 wt% (= 1 000 ppm) is possible but depends on a variety of constraining factors including overall limits of detection. This makes the method less suitable when questions of trace oxide patterns are addressed.

The **LA-ICP-MS technique** differs fundamentally from EPMA, as it is not based on X-rays emitted from excited atoms. Instead, this method is based on the capacity of charged particles to be separated according to their specific mass-to-charge ratios which correspond to particular chemical elements (Artioli 2010). Detection and counting the individual particles (i.e. ions) allows ‘what should be the best possible analytical sensitivity’, and therefore mass spectrometry is generally accepted as ‘the ultimate analytical tool’ (Pollard et al. 2007, 160). ICP-MS is one of the varieties of mass spectrometry, where an inductively coupled plasma (a plasma generated through ionizing flow of gas, Ar, heated by electromagnetic induction) is used as a source of ionisation of the sample (i.e. converting atoms from the sample into charged ions). A wide range of experimental configurations exist to present the sample material to the ionizing gas stream, resulting in various complex combinations of devices. In general ICP-MS instruments are commonly considered as very efficient means for trace elemental analysis, and producing reliable compositional characterisation down to and below part per million levels, while it can be less accurate at higher concentrations, i.e. major oxides. The particular technique applied for the current study is the so called high resolution ICP-MS (HR-ICP-MS), where the mass spectrometer compartment of the overall instrumentation is optimised by a double-focusing magnetic sector mass analyser, and a three stage detector system (B. Gratuze pers. comm.). Furthermore, the mode of operation with a laser beam ablation (LA) of solid material being used to introduce the sample into the plasma has many practical advantages, in contrast to the solution based ICP-MS technique which requires pre-treatment and digestion of the solid sample. In essence, during LA-ICP-MS analysis the laser beam is focused on the sample, evaporating only a minute amount of ablated material, which is then swept away with a gas stream (usually Ar as a carrier gas) to the ICP-MS system, and consequently processed and analysed. With this technique only minimal sample preparation (or even no sample preparation) is needed, as far as the analysed piece
can fit into the ablation cell of the instrument, which also does not need to be under vacuum. The problems of surface weathering of ancient glass, that usually significantly changes the original composition, can be eliminated by a short pre-ablation of the sample. Such a pre-treatment removes the superficial layer in a minute area and provides access to the unaltered material underneath the corrosion. The laser beam leaves small craters on the surface of the sample, depending on its frequency and the duration of the ablation. Generally, the small size of the craters (c. 60-100 μm diameter, 250 μm depth, B. Gratuze pers. comm.) makes them macroscopically invisible, and the technique is defined as ‘almost completely non-destructive’ (Gratuze 2013a, 204). At the same time, the practical implementation of the measurements has been described as ‘cheap and very fast’ (Shortland et al. 2007), compared to some other methods. In spite of these advantages, LA-ICP-MS analysis may have certain problems when it comes to precise quantification (ICP-MS documents). For instance, the results can be affected by element fractionation which occurs during the laser interaction with the sample. That is the selective removal of certain elements, which affects their signal strengths, therefore may cause misrepresentation of the actual values (Gratuze 2013a).

II.2.1.2. Particular instrumental settings and analytical runs

The general principles of EPMA and LA-ICP-MS techniques, as described above, are valid for all such instruments, but are further modified by the particular laboratory settings. A detailed account of the analytical sets, sample preparation, operating conditions, and data acquisition parameters for the current project is outlined below.

The present research is based on compositional data obtained from 199 samples in total, including 83 samples analysed by both EPMA and LA-ICP-MS methods, 70 samples analysed by LA-ICP-MS only, and 46 samples analysed by EPMA only (Tables II.1.-II.3.). All the EPMA analyses and, respectively, all the LA-ICP-MS analyses were carried out using one and the same instrumental setting for each technique, in order to ensure a sufficient level of reproducibility between different analytical runs.

The EPMA sample preparation and measurements were done in the Wolfson
Archaeological Science Laboratories of the UCL Institute of Archaeology. Small cross sections were removed from the glass fragments, mounted in cold-setting resin blocks and polished with increasingly finer grades of abrasive agents, down to 1 μm size diamond paste. The polished surface was carbon coated in order to provide electrical conductivity. The measurements were performed with a JEOL 8100 electron microprobe instrument. Operating conditions were 15 thousand volts (kV) accelerating voltage, a beam current of 50 nano-amps (nA), and the beam of electrons analysing an area of approx. 150 μm$^2$, at magnification 800x. Typically, the measurement time was 60 sec on peaks and, respectively, 20 sec on backgrounds either side of the peak, with certain variations for some of the elements analysed. Five to ten such small area scanning measurements were taken on each sample, and 23 to 25 (up to 27) elements were routinely sought, with analytical totals reaching about 98-100 wt%. The individual results were calculated as weight percent (wt%) oxide values using stoichiometry rather than measured oxygen content, and processed using a ZAF correction programme to account for the matrix composition. The individual five to ten measurements for each sample were then averaged to obtain a representative mean value, reporting the original analytical totals without normalisation to 100 wt%.

The LA-ICP-MS measurements were carried out at the Institute de Recherche sur les Archéomatériaux (IRAMAT), Centre Ernest Babelon, CNRS, Université d’Orléans, France. The same polished cross sections mounted in resin blocks for the EPMA measurements were used in the LA-ICP-MS instrument when analysing all the samples from Dichin assemblage, and a few samples from the Odartsi assemblage and Samokov (as indicated in Tables II.1., II.2., samples G 4-10). The rest of the LA-ICP-MS data were obtained from loose samples, size c. 3-6 mm, fixed in the ablation cell of the setup. No preparation was done, except simple removing of the samples from the original...
<table>
<thead>
<tr>
<th>Total 80 samples</th>
<th>EPMA 2007</th>
<th>EPMA 2010</th>
<th>LA-ICP-MS 2010</th>
<th>LA-ICP-MS 2012</th>
<th>EPMA 2012</th>
<th>EPMA 2013 I</th>
<th>EPMA 2013 II</th>
</tr>
</thead>
<tbody>
<tr>
<td>G 1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>G 2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>G 3</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>G 11</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>G 12</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>G 13</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>G 14</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>G 15</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>G 16</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>G 17</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>G 18</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>G 19</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>G 20</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>G 21</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>G 22</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>G 23</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>G 24</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>G 25</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>G 26</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>G 27</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>G 28</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>G 29</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>G 30</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>G 31</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>G 32</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>G 33</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>G 34</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>G 35</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>G 36</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>G 37</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>G 38</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>G 39</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>G 40</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>G 41</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>G 42</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>G 43</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>G 44</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>G 45</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>G 46</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>G 47</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>G 48</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>G 49</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>G 50</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>G 51</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>G 52</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>G 53</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>G 54</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>G 55</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>G 56</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>G 57</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>G 58</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>G 59</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>G 60</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>G 61</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>G 62</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>G 63</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>G 64</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>G 65</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>G 66</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>G 67</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>G 68</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>G 69</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>G 70</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>G 71</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>G 72</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>G 73</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>G 74</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>G 75</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>G 76</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>G 77</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>G 78</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>G 79</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>G 80</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>G 81</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>G 82</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>G 83</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>G 84</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>G 85</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>G 86</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>G 87</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Table II.1.** Sequence of the analytical runs (EPMA and LA-ICP-MS) of the Dichin set (80 samples in total).
Table II.2. Sequence of the analytical runs (EPMA and LA-ICP-MS) of the Odartsi set, and G 4 – a single sample from the 'Samokov' site (60+1 samples in total).
<table>
<thead>
<tr>
<th>PLD 1</th>
<th>LA-ICP-MS 2012 23 samples</th>
<th>LA-ICP-MS 2013 23 samples</th>
<th>EPMA 2013 (III) 22 samples</th>
</tr>
</thead>
<tbody>
<tr>
<td>SER 1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SER 2</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SER 3</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SER 4</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SER 5</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SER 6</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SER 7</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SER 8</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SER 9</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SER 10</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SER 11</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SER 12</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SER 13</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SER 14</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SER 15</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SER 16</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SER 17</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SER 18</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SER 19</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SER 20</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SER 21</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SER 22</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SER 23</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SER 24</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SER 25</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SER 26</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SER 27</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SER 28</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SER 29</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SER 30</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SER 31</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SER 32</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SER 33</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SER 34</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SER 35</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SER 36</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SER 37</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SER 38</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SER 39</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SER 40</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SER 41</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SER 42</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SER 43</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SER 44</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SER 45</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SER 46</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SER 47</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SER 48</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SER 49</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SER 50</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SER 51</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SER 52</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SER 53</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SER 54</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SER 55</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SER 56</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SER 57</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table II.3. Sequence of the analytical runs (EPMA and LA-ICP-MS) of the Serdica set, and PLD 1 – a single sample from Philippopolis (57+1 samples in total).
fragments with a thin rotating blade. Preferably, the fresh cross section sides of the samples were ablated in order to minimise the effect of surface weathering. The laser beam used is based on a Nd:YAG (neodymium-doped yttrium aluminium garnet) technology, working at 266 nm at a quadrupled frequency in the ultraviolet region (VG UV-Microprobe laser system), using 6 to 8 Hz laser pulse frequency, with Ar carrier gas. The measurements were performed using an Element XR mass spectrometer, Thermofisher Instruments. The procedure consisted of 20 sec time for pre-ablation, followed by 50 sec for analysis, regular blank runs, and other routine practices (B. Gratuze pers. comm.). Each sample was analysed at two different spots, the concentrations were calculated following an in-house algorithm, and the results then were typically averaged in order to obtain mean values representative for the particular sample. Routinely, data for 55 to 58 elements were acquired.

As mentioned previously, the present research comprises 197 samples, originating from three different site assemblages, plus two additional samples (see Sections III.1.2., IV.1.2., V.1.2. and Appendix A.8. about the assemblages and the sampling strategy), and the analytical work was done in several runs, from 2007 to 2013 (Tables II.1.-II.3.). Firstly, in 2007, EPMA analyses of 17 samples from Dichin, Odartsi and Samokov were performed (EPMA 2007 run), followed by another large group of all the remaining 70 samples from Dichin (EPMA 2010 run). A few months later, all the samples from the EPMA 2007 run and several samples from EPMA 2010 were measured by LA-ICP-MS technique (LA-ICP-MS 2010 run, in total 37 samples). In 2012, after the start of the current project, 6 samples from Dichin were re-analysed by EPMA, as a small test run (EPMA 2012 run). In the same year, another series of LA-ICP-MS analyses was performed on 53 Dichin and Serdica samples (LA-ICP-MS 2012 run). In the beginning of 2013, in two consecutive runs, some more Dichin samples were re-analysed: EPMA 2013(I) run consisting of 9 samples, and EPMA 2013(II) run consisting of 15 samples. The LA-ICP-MS analyses in 2013 included 63 samples from Odartsi and Serdica, and a single sample from Plovdiv (LA-ICP-MS 2013 run), followed in the end of the year by the last EPMA series of 42 samples from the Odartsi and Serdica assemblages (EPMA 2013(III) run).
It needs to be clearly pointed out that such time-fragmented layout of the analytical work has particular disadvantages, especially regarding the data match between the different runs. The overall pattern presented in Tables II.1.-II.3. results from many factors, including access to the materials for sampling, availability of the analytical instruments, integration of diverse sampling approaches, etc. Therefore, a critical comparison of these multiple runs, even if they were performed under nearly identical conditions, is essential. An evaluation of the extent of their match or mismatch allowed for the identification of certain issues. These are specific for each of the techniques, or concern the comparisons between the techniques, and are discussed both from practical and methodological points of view (see Sections II.2.1.3. and II.2.1.4.). Accordingly, all this represents a positive outcome, which otherwise would not be possible if only one-off analytical series for each technique were performed.

**II.2.1.3. Data quality assessment**

Both the EPMA and the LA-ICP-MS techniques require careful and regular monitoring of the operating conditions, calibration of the setup, corrections for instrumental drift, use of standard reference materials, etc., in order to maintain reliable functioning and results (Pollard et al. 2007). The overall theoretical abilities of the methods and instruments for detection and quantification of the oxides present in glass, as described above, have their practical aspects which may vary between different analytical runs because of numerous factors. According to the routine procedure, reference materials with known compositions were measured as unknowns along with the actual samples in each analytical run, to enable an objective assessment of the data quality and an effective comparison between the runs. The following paragraphs summarise the conclusions drawn from an evaluation of these analyses.

Two of the Corning archaeological reference glasses, Corning A and Corning B, were used for the standard measurements during the EPMA and the LA-ICP-MS analytical runs for the current research. This set of synthetic materials has been produced on behalf of the Corning Museum of Glass, USA, to replicate the main compositions of ancient glasses and to facilitate analytical research by providing the
necessary matrix resemblance (Brill et al. 1999-2012; Vicenzi et al. 2002; Wagner et al. 2012). Both Corning A and Corning B were measured in the EPMA runs, while only Corning A was used in the LA-ICP-MS runs since in this case Corning B is included in the internal instrumental calibration of the setup (B. Gratuze pers. comm.). Most often, four to ten individual area scans were taken during each EPMA run, and results were averaged as representative for the particular run*. The procedure of the LA-ICP-MS analyses is different since more frequent monitoring of the reference material is required there. Even though, four to six measurements (each of them as an average of two spot ablations) typically correspond to the particular moment when the actual samples from the current project have been analysed. In an attempt to avoid further complications these four to six results per run are averaged as summarised means for each LA-ICP-MS run, similarly to the EPMA. The full data are presented in Appendix B.1.1., along with the published compositions of the reference glasses.

The assessment of the results follows the concepts of precision and accuracy (strictly speaking – of repeatability and trueness) as fundamental aspects of scientific measurements and data treatment, which ensure an internal relative evaluation, and an absolute evaluation of analytical quality (Artioli 2010; Pollard et al. 2007, 313; AMC Technical Brief 2003). The series of comparisons in Figures II.2.-II.5. between the runs present the repeatability (i.e. the extent of dispersion/mismatch between the individual measurements on the same sample, expressed as relative standard deviation in percentages; lower RSD% = less mismatch = better repeatability) and trueness (i.e. the extent of agreement between the averaged analytical results and the accepted values of the reference glasses, expressed in percentages as difference relative of the reference values; Δ rel. % closer to zero = less disagreement = better trueness). The data are presented separately for the major oxides (Fig. II.2.; II.3.), and for the full range of major, minor and trace oxides (Fig. II.4.; II.5.) in Corning A and Corning B in an attempt to illustrate both the details and the overall pattern. Assuming

* The original data for the EPMA 2007 run have been assessed as reliable at the moment of the analyses, but were not available anymore when the current project started, and are therefore not presented in Appendix B.1.1. The first measurement for the EPMA 2010 run of both Corning A and Corning B is only formally presented, but not included in the calculations due to its flaws which distort the overall results. The EPMA 2012 run has only a single analysis of each reference glass, as it was performed as a test run. The magnitude of uncertainty typical for the EPMA 2007 and EPMA 2012 runs is illustrated in Appendix B.1.1., using actual sample measurements (Fig. II.6., II.7.).
Fig. II.2. Comparison of the analytical runs’ repeatability expressed as relative standard deviation of the measurements of Corning A and B glass standards (major oxide suites in descending order of their concentrations as indicated in Vicenzi et al. 2002, Table 1). Full data in Appendix B.1.1.
Fig. II.3. Comparison of the analytical runs’ trueness expressed as relative difference from the accepted reference values of Corning A and B glass standards (major oxide suites in descending order of their concentrations as indicated in Vicenzi et al. 2002, Table 1). Full data in Appendix B.1.1.
Fig. II.4. Comparison of the analytical runs’ repeatability expressed as relative standard deviation of the measurements of Corning A and B glass standards (full oxide suites in descending order of their concentrations). Full data in Appendix B.1.1.
Fig. II.5. Comparison of the analytical runs’ trueness expressed as relative difference from the accepted reference values of Corning A and B glass standards (full oxide suites in descending order of their concentrations). Full data in Appendix B.1.1.
that the measurements become less precise and less accurate when limits of detection
are approached, the oxides are arranged in descending order of their concentrations in
the reference glasses, following the values given in Vicenzi et al. (2002, Table 1).

The aim of these comparisons is not only to produce a clearer visual
representation of the analytical quality, but mostly to draw conclusions regarding the
general question of how all the data obtained throughout the runs should be
approached, combined, and/ or selected, so that the final interpretations would be
based on sufficiently consistent and reliable primary results. The following points need
to be discussed, when this question is addressed:

1. Identification of any problematic issues in the overall dataset, and, as
appropriate, their correction, or exclusion from the database. Here a comprehensive
comparison between the EPMA and LA-ICP-MS techniques is important, but the focus
is on the performance of particular runs rather than on a generalised juxtaposition of
both methods (as discussed in Lankton et al. 2014).

2. Justified outline of a group of diagnostic oxides, with discriminative and
interpretative significance. These also should demonstrate sufficiently good
experimental repeatability and trueness throughout the analytical runs, and well
corresponding results both in EPMA and LA-ICP-MS measurements. Such a diagnostic
group of variables would allow data from all the runs to be successfully compared and
combined for further processing and interpretation.

As expected, the EPMA runs demonstrate overall good levels of repeatability
and trueness in the major oxide range (Fig. II.2.B., C.; Fig. II.3.B., C.); in most of the
cases RSD is within 5%, and Δ relative within ± 5%. However, the measurements for the
EPMA 2010 run indicate significant problems, which was the reason for re-analysing
many of the Dichin samples (Table II.1.). The most serious errors occur in antimony
results (both repeatability and trueness), and manganese, which was measured much
lower than the Corning A reference value. Alumina values are also typically lower
compared to the reported concentration in Corning B. The same problem, to a lesser
extent, is identified for the magnesia results, which are slightly lower for both Corning
reference glasses. The good consistency throughout all the other EPMA runs, except
the higher values of alumina and lower values of magnesia in EPMA 2013(I) and EPMA 2013(II), indicate that these are issues of the particular performances, rather than problems of the method or the instrument.

Going down to the range of minor oxides for the EPMA runs, the repeatability generally deteriorates. This is because the limits of detection for this technique are approached (Fig. II.4.B., C.), even if the results for many of the oxides are still acceptably close to the reference values, with Δ relative around ±10-15% (Fig. II.5.B., C.). Expectedly, for values below 0.1 wt% both repeatability and trueness are erratic, with a clear correlation between the concentration of the oxides and the extent of precision in their measurements. However, the lower analytical quality of the EPMA 2010, compared to the other runs, becomes obvious in the minor oxides range, as well (Fig. II.4.C. – SO₃, Sb₂O₅). Certain minor oxides, such as P₂O₅ or SrO may look plausible in 0.1-0.01 wt% concentrations when compared to their reference values (Fig. II.5.B., C.), but the degree of mismatch in the repeatability in their measurements (Fig. II.4.B., C.) indicates that their quantification with the EPMA needs to be taken cautiously. On the other hand, any generalised statements about the appropriateness of this technique in the lower range values would not be correct, since element-specific factors such as excitation characteristics and overall matrix effects should not be ignored. Results for titania, iron oxide, and manganese, for example, show that in the minor oxide range they can be successfully determined (again, the lower EPMA 2010 data for manganese in Corning B is not representative for the ability of the method), and the figures for titania in Corning B are even below 0.1 wt%, allowing for certain margins of error (Fig. II.5.C.).

The **LA-ICP-MS runs** can be checked against Corning A reference glass only, which, to a certain extent, limits the conclusions about soda, lime and alumina measurements. Overall, the graphs presenting repeatability and trueness in these runs look ‘more even’ than the pattern of the EPMA data. This is due to the much higher sensitivity of the LA-ICP-MS technique and the particular methodology of its use applied in IRAMAT. However, in the major oxide range of the LA-ICP-MS 2010 run the

---

*P₂O₅ in EPMA 2010 and EPMA 2013(II) runs seems problematic, and is therefore considered as an issue of the particular performances, not of the technique.*
results for alumina, and probably lime, are questionable, especially with poor reproducibility and lower measurements of Al$_2$O$_3$ compared to the reference value (Fig. II.2.A.). The LA-ICP-MS 2012 run demonstrates certain problems with lime and antimony, and all the runs have Δ relative worse than -5% for magnesia data. At the same time, the LA-ICP-MS 2013 run looks quite similar to the EPMA graphs, with repeatability within RSD 5% and within nearly ±5% Δ relative of Corning A values. This indicates that the technique can generally be considered as reliable for the entire scale of values, and should not only be used for trace elements characterisation only. However, the EPMA vs LA-ICP-MS comparison of the actual samples of this run still leaves some doubts about the results for soda, lime and alumina (see Section II.2.1.4.; Fig. II.11.), as also pointed out elsewhere (Lankton et al. 2014).

The LA-ICP-MS results for the oxides with concentrations lower than 1 wt% in Corning A show that all the runs are consistent, following nearly identical pattern of trueness, which is an evidence for the stability of the analytical procedures (Fig. II.5.A.). Certain problems are obvious in titania measurements in the LA-ICP-MS 2010 run, which have Δ relative of about -15% (Appendix B.1.1.). Some other oxides constantly show even greater Δ relative values (PbO, ZnO, Cr$_2$O$_3$) throughout all the runs; these are not issues of a particular performance but results of the overall method potential, related to element fractionation, etc. (Gratuze 2013a).

![Fig. II.6. Uncertainty of the EPMA measurements of an actual sample, in descending order of oxide concentrations. Major oxides: SiO$_2$, Na$_2$O, CaO, Al$_2$O$_3$, Fe$_2$O$_3$, Cl, MgO; minor oxides: TiO$_2$, K$_2$O, SO$_3$; trace oxides: MnO, SrO, PbO, BaO, Cr$_2$O$_3$, V$_2$O$_5$, CuO, ZnO, NiO, CoO, PbO. Not included here: Sb$_2$O$_3$, SnO$_2$, As$_2$O$_3$ – not detected, ZrO$_2$ – not measured.](image-url)
Finally, the degree of uncertainty (i.e. the dispersion of the values seen when a particular quantity is repeatedly measured) as a characteristic of particular results from the EPMA 2007 and 2012 runs is illustrated by the measurements of two actual samples with distinct compositions (Fig. II.6., II.7.). It is seen as helpful since there were not sufficient data from the reference glass analyses in these runs, based on which the general repeatability can be assessed. The graphs show that the major and minor oxides can be steadily measured by EPMA, while distortions start in the trace oxide range. At the same time, conclusions about the reliability of the technique must be based on a detailed evaluation of multiple factors. For example, manganese in HIT composition is present normally only at trace levels, but it can be still successfully determined by EPMA, with an uncertainty of the measurements articulated as c. 15% RSD (Fig. II.6.), also confirmed by the comparison of the EPMA and LA-ICP-MS results (see Section II.2.1.4.). The application of this data for further interpretations is acceptable, while the result for strontium oxide in HIMT composition (the second example) is more likely to represent an approximation than a reliable quantification. In this case, strontium oxide has a similar position and even higher absolute concentration (Fig. II.7.) compared to MnO in the previous graph (Fig. II.6.), i.e. it is quantitatively best presented within the trace oxide range, with an absolute...
concentration of 0.07 wt%. However, its nearly double RSD of c. 30% (compared to 15% RSD of MnO in HIT composition, the previous example) may indicate a higher uncertainty of the data, which, therefore, has to be treated with caution (see Section II.2.1.4., Fig. II.9.). Thus, the overall observation that the uncertainty of EPMA raises with the decrease of the absolute concentrations needs further clarifications regarding particular matrices and oxides, as well as regarding the required interpretative resolution of the data within the intermediate section between the minor and the trace oxide ranges.

As already mentioned, the present discussion is focused on the assessment of the analytical quality of the specific runs performed for the current project, rather than on a presentation of an overall comparison of the potential of the two techniques. However, attention should be given to that second aspect as well.

The general postulate that EPMA is a technique which reliably determines the oxides within the major and minor ranges in glass composition while LA-ICP-MS has significantly lower limits of detection is well illustrated in the graphs showing the analytical runs’ repeatability and trueness, as discussed above (Fig. II.2.-II.5.). The intention of these graphs and the associated comments is to summarise the information regarding the way in which the particular runs should be assessed. At the same time, it should be reminded that these graphs are based on data obtained in two different laboratories which follow their different practices and methodologies. Therefore, any attempts to directly draw conclusions about an inter-method comparison, without taking these inter-laboratory distinctions into consideration could be incorrect.

Alternative representations of the repeatability of the EPMA and LA-ICP-MS measurements of the Corning glass standards are based on a different approach in data averaging (Fig. II.8.). Following the methodology of the microprobe analysis at the Wolfson Archaeological Science Laboratories, a single result represents an average of five to ten individual measurements. This implies considerably longer measurement time as opposed to the routine practice in IRAMAT where a single result is an average of only two individual ablations. Therefore, when comparing the values of RSD
representative for each technique (i.e. not evaluating the performance of a certain run), the EPMA data has to be calculated as an average of several particular runs (each as a mean value of the individual measurements) instead of an average of the individual measurements within the run. In this way, the repeatability of the EPMA technique is correctly presented, and for some of the oxides RSD is significantly lower than the values in Fig. II.4., even if the problems of the analytical quality are still visible.

**Fig. II.8.** Alternative representations of the analytical runs’ repeatability calculated according to the accepted practices in the Wolfson Archaeological Science Laboratories and IRAMAT. Details in the text; full data in Appendix B.1.1.
A detailed inter-method comparison between the potentials of the EPMA and LA-ICP-MS techniques may also need to consider some other differences in the methodologies of the two laboratories, such as the use of different types of internal standards for the calibration of the setup. While the procedure at IRAMAT is based on the application of glass standards only, the practice at the Wolfson Archaeological Science Laboratories is to use mineral or pure element standards (B. Gratuze, K. Reeves pers. comm.). However, as already pointed out, the aim here is not such an extensive inter-method comparison but mostly an evaluation of the particular data in the project.

Going back to the initial points of the present discussion, it can be concluded that the EPMA 2010 run demonstrates multiple issues of performance, and, when possible, for all the samples analysed several times other data from the EPMA and LA-ICP-MS runs will be preferred. When in the absence of later data the EPMA 2010 results are used, corrections for alumina, manganese, and magnesia are done in order to bring the data in line with the standards, as marked in Appendix B.1.1. Alumina values are corrected also for the EPMA 2013(I) and 2013(II) runs, while measurements for phosphorus from the EPMA 2010 and EPMA 2013(II) should not be considered. In the LA-ICP-MS runs some of the major oxide data are used with caution, and when possible the EPMA results are preferred for Na₂O, Al₂O₃, and CaO. In particular, antimony in LA-ICP-MS 2012 and titania in LA-ICP-MS 2010 are questionable, but the data are still taken into account without corrections, since most of the absolute values are relatively low, <0.5-0.6 wt%.

Regarding the second point, that is justified definition of a group of diagnostic oxides comparable throughout the entire dataset (i.e. equivalently in EPMA and LA-ICP-MS measurements), the reference results indicate that magnesia, iron oxide, and manganese as measured in Corning A by LA-ICP-MS are the most reliable major oxides for this technique, in terms of repeatability and trueness (Fig. II.2.A., II.3.A.). In general, the EPMA results confirm this observation*, even in Corning B composition, where MnO and Fe₂O₃ are both present as minor oxides (see also Fig. II.6.). Titania is the

* The quality of the EPMA 2010 results for MnO and MgO is not representative here.
fourth oxide to be included here. It has been recognised as a good discriminator for most of the glass compositions of Late Antiquity (Foy et al. 2003, Fig. 2), and in the actual samples of the present study it is found approximately within the range of 0.05–0.70 wt% where the EPMA method gives stable and consistent results for it. Thus, magnesia, iron oxide, manganese, and titania form a suite of variables which are most likely to be reliably measured both with EPMA and LA-ICP-MS, and which also provide the interpretative significance needed when conclusions are inferred from the primary data. The importance of other oxides from the major and minor ranges (i.e. accessible for both techniques) such as alumina, lime, soda, and phosphate is not lessened at that point**, but certain issues in their quantification with either of the methods, as previously outlined, do not allow a thorough combined processing and interpretation of all the analytical runs.

**II.2.1.4. A comparison of EPMA and LA-ICP-MS data – evaluation of practical problems and interpretative significance**

As already pointed out, nearly half of the samples in the present project (83 samples out of 199 in total) were analysed using both the EPMA and LA-ICP-MS techniques (Tables II.1.-II.3.), and hence providing a large database for recognizing parallels and contrasts. After discussing the results obtained from the Corning reference glasses with these two methods (see Section II.2.1.3.) an attempt to outline the comparability of both techniques based on data from the actual samples is presented below.

A significant number of recent analytical studies on Roman and late antique glass follows a conventional scheme of determining major and minor oxides by EPMA/SEM-EDX, and traces by LA-ICP-MS (for example Cagno et al. 2014; Schibille et al. 2012b). The application of the latter technique is often seen as ‘complementary’ to some other analytical approaches, such as XRF or EPMA (Gallo et al. 2013, 2592), without efforts to explore the intersection of the methods. In the present study, however, the necessity to achieve a sufficiently consistent and unified database of

** Other compounds or elements, such as K₂O, Sb₂O₃, Cl should also be mentioned here, but again, due to issues of quantification, or generally lower discriminative potential in this particular research they were not included in the present group; SO₃ is not considered as it cannot be determined by LA-ICP-MS.
primary results using all the analytical runs provides the opportunity to compare and
investigate the way in which EPMA and LA-ICP-MS data from actual samples
correspond to each other. As mentioned previously, the main goal here is not a
comparison of the abilities of both methods in general, but an evaluation of the
practical problems in the present research, and their implications at the level of data
interpretation.

Appendix B.1.2. presents the primary data for all 83 samples measured twice,
providing pairs of their EPMA* and LA-ICP-MS results. The selection of the oxides in the
appendix is an outcome of preliminary work and data comparison. For convenience, all
the major and minor oxides are included**; however some of them are not compared
in detail, because of limited diagnostic significance (SiO₂, K₂O, Cl), or distortion of the
EPMA values (P₂O₅) due to problems of particular runs and/ or values too close to the
detection limits established for this method. Strontium oxide is an example of how the
EPMA data around and below 0.1 wt% can be mostly indicative, rather than reliably
quantitative (i.e. well interpretable in details) when compared to the LA-ICP-MS
measurements for the same concentrations (Fig. II.9.). Therefore, after the initial
comparison and assessment of the reference measurements (see Section II.2.1.3.), all
the SrO results from the EPMA runs were removed from the entire database, and are
not reported in the appendices.

Taking into account that comparability of both techniques has to be effectively
assessed for particular compositions and/ or analytical runs, a subsequent allocation of
the 83 repeated samples into three main groups was done (Appendix B.1.2.). The
following graphs (Fig. II.10.-II.14.) present a juxtaposition of the EPMA versus the LA-
ICP-MS pairs of values within these three groups, with reference mostly for the
diagnostic oxides as outlined above (see Section II.2.1.3.). The purpose of these graphs
is to visualise and quantify the extent to which both datasets obtained by different
techniques correspond to each other. As an outcome, stable matches but also
pronounced discrepancies are identified. Since the aim is to keep any additional re-

* Some of the original EPMA values are corrected as discussed in Section II.2.1.3., and indicated in
Appendix B.1.1.
** Except for SO₃ which cannot be analysed by LA-ICP-MS, hence cannot be included in a comparative
work, and Sb₂O₃ which in the majority of the samples is present in trace concentrations.
A. Working stage of the assessment of SrO results in Dichin samples plotted against identical iron oxide values: the upper graph represents much clearer clustering of the LA-ICP-MS data; the lower graph shows the blurred pattern of the EPMA data (the labels of the compositions correspond to a particular stage of data processing, and are for guidance only).

Fig. II.9. Working stage of the assessment of SrO results in Dichin samples plotted against identical iron oxide values: the upper graph represents much clearer clustering of the LA-ICP-MS data; the lower graph shows the blurred pattern of the EPMA data (the labels of the compositions correspond to a particular stage of data processing, and are for guidance only).
calculations or manipulations of the primary results as limited as possible, no formulae for correcting the data are suggested here (in contrast to Paynter 2006, for example). On the contrary, a justified choice is made for each oxide – to combine measurements obtained by both technique, or, to use either of the datasets, as discussed below. To quantify the extent of accordance between the EPMA and the LA-ICP-MS values, basic tools of linear regression analysis are applied. Since the intercept of the regression line is intentionally set at 0.00, the regression equations are reduced to $y=bx$ (Shennan 1997). In summary, the regression equation presents the direction of the regression line (ideally, $y=1x$, i.e. EPMA and LA-ICP-MS values fully overlap), and the coefficient of determination indicates the strength of the correlation (ideally, $R^2=1$, i.e. all the data fit the regression line).

The first group of comparisons includes all the samples measured in the EPMA 2013(III) and the LA-ICP-MS 2013 runs, with some additional data from the LA-ICP-MS 2012 run, and all the Levantine I composition samples from Dichin. The graphs for titania, manganese, iron oxide, and magnesia (Fig. II.10.) confirm that these oxides demonstrate most stable and consistent results in both techniques, and moreover – a consistency identified throughout all the ranges of concentration. The value of $R^2\geq0.988$ in these cases indicates nearly no scattering around the regression lines. The slopes of the lines also prove a good match between both datasets, with TiO$_2$ measured slightly higher by EPMA, compared to the LA-ICP-MS values, and the opposite observation for Fe$_2$O$_3$. However, such minor discrepancies are expected and cannot affect the overall conclusion – that for the samples from this group the EPMA and LA-ICP-MS results for the diagnostic oxides can be seen as interchangeable. Accordingly, the data processing and interpretation of the Odartsi and Serdica samples (Tables II.2., II.3. – last two columns only) would not be biased by the application of particular techniques, or affected by the differences between the runs. However, the same samples compared as soda, alumina, and lime values (Fig. II.11.) have again very little diversion of the slopes, but considerably wider spread of the data around the regression lines ($R^2\leq0.858$). This does not mean that the quality of the results has to be doubted. It rather suggests that these values, even if they represent some of the most important oxides in glass composition, cannot be taken as leading indicators when the
interpretations are based on detailed quantification. The EPMA data are likely to be preferable when samples are analysed twice, and the LA-ICP-MS values will be used as indicative only. It should be pointed out that Na$_2$O, Al$_2$O$_3$, and CaO in this first group illustrate probably the best match of these oxides compared to the rest of the data in the other two groups. Consequently, their detailed comparison will not be discussed further.

The **second group** of juxtapositions consists of samples with HIT and HIMT composition from Dichin and Odartsi. They were analysed in the EPMA runs 2007, 2013(I), 2013(II), plus only two samples from the EPMA 2010 and EPMA 2012 runs, and, respectively, the LA-ICP-MS 2010 and 2012 runs. The main issue in this group are titania values which demonstrate significant discrepancies. When the EPMA 2007 run
is plotted separately (Fig. II.12.A. – red triangles), it is evident that the data are strongly correlated, but the direction of the slope indicates systematically higher EPMA values. A possible explanation of this are the lower measurements of titania in Corning A for LA-ICP-MS 2010 run (see Section II.2.1.3.). However, the rest of the samples of the LA-ICP-MS 2010 run are well accordant with the other EPMA runs, and at the same time, the EPMA 2007 values of titania are the (unrealistically?) highest measured in this study (reaching nearly 0.8 wt%). The solution preferred here is to ignore the EPMA 2007 values of titania, and to take the LA-ICP-MS data as valid for these samples. With such a correction all the data become unified and well correlated (Fig. II.12.B.).

The comparison for manganese in the second group demonstrates an overall good match between both datasets, except the single sample from the EPMA 2010 run (Fig. II.12.C. – indicated by a red triangle). When the problematic MnO values in the EPMA 2010 reference measurements are remembered (Fig. II.3.B.), again, the LA-ICP-
**A.**

\[ y = 0.8539x \]
\[ R^2 = 0.965 \]

**B.**

\[ y = 0.9705x \]
\[ R^2 = 0.9734 \]

**C.**

\[ y = 0.9741x \]
\[ R^2 = 0.9932 \]

(EPMA 2007 replaced with LA-ICP-MS values on X-axis)

**D.**

\[ y = 0.9886x \]
\[ R^2 = 0.9837 \]

**E.**

\[ y = 1.006x \]
\[ R^2 = 0.8165 \]

**F.**

\[ y = 1.0779x \]
\[ R^2 = 0.6399 \]

**Fig. II.12.** HIMT and HIT samples (Dichin and Odartsi) – comparison of the EPMA 2007, 2010, 2012, 2013(I), 2013(II) runs, and the LA-ICP-MS 2010, 2012 runs. The red triangles indicate problematic points in the dataset discussed in the text, rather than any particular compositional group.
MS results for manganese in that particular sample should be used, instead of the EPMA 2010 value.

The iron oxide for the same set of juxtapositions is sufficiently well correlated in terms of EPMA versus LA-ICP-MS values (Fig. II.12.D.). Yet in further data processing the microprobe data will be used, so that the rest of the HIMT samples not analysed by LA-ICP-MS could be fully compatible within the overall compositional group.

The last two comparisons in this group of HIT and HIMT composition samples show rather dispersed and weakly correlated EPMA and LA-ICP-MS results. As already discussed, the microprobe values for alumina seem more convincing (Fig. II.12.F.), and therefore are preferred in the dataset. However, following the reasoning so far, magnesia is supposed to be equally well determinable by both techniques in the present project (Fig. II.12.E.). The correction of the EPMA 2010 values of MgO is based on the reference measurements and generally poor analytical quality of this run (see Section II.2.1.3.), but when we go back to the reference data, apparently, the EPMA 2013(I) and 2013(II) runs would need a similar adjustment for the same reason (Fig. II.3.B.). Therefore, in an attempt to avoid modifications in the primary database and to keep it unified when possible, the LA-ICP-MS results for magnesia will be entirely used for this group of comparison instead of the microprobe values*.

The third group of comparison includes the most problematic data in the study from the EPMA 2010 run, and two samples from the EPMA 2013(II), plotted against the LA-ICP-MS values from 2010 and 2012 runs. In terms of chemical pattern these are samples presenting 5th c. Mn-decolourised composition and 6th century composition. The only relatively stable correlation here is iron oxide where both techniques provide very close values (Fig. II.13.B.). Likewise the previous groups of juxtapositions, the microprobe data for iron oxide will be used.

Here the graph of titania is probably the worst example of inter-method comparability in this work, with clear problems for the 6th c. composition samples (Fig. II.13.A). Presumably, it illustrates issues (both systematic and random errors) in the correction of the EPMA 2010 results for magnesia is made (Appendix B.2.2.).

* For samples not measured with LA-ICP-MS (samples G 39-41) a re-calculation of the EPMA 2013(I) results for magnesia is made (Appendix B.2.2.).
Fig. II.13. Dichin samples (5th c. Mn-decolourised and 6th c. compositions) – comparison of the EPMA 2010, 2013(II) runs, and the LA-ICP-MS 2010, 2012 runs. The red triangles indicate problematic points in the dataset discussed in the text, rather than any particular compositional group. The circles in graph D. present a combined use of EPMA and LA-ICP-MS data for titania as a possible solution of the data quality problem (details in the text).
EPMA 2010 data generation which cannot be fully recognised using the Corning reference glasses only. For a better consistency of the data, the LA-ICP-MS values for the 6th c. composition should be used instead of the EPMA 2010 run. However, for the samples of 5th c. Mn-decolourised composition the discrepancies are lower (even again with poor strength of correlation) because of the lower absolute values of titania. Since the 5th c. composition group from Dichin contains samples not analysed by LA-ICP-MS, an attempt is made to compare all 5th c. composition samples (i.e. all the samples analysed by EPMA and LA-ICP-MS, plus all the samples analysed by EPMA only) using Fe$_2$O$_3$ versus TiO$_2$ plots. The first graph represents the pattern when only the EPMA TiO$_2$ results are used for the 5th c. samples (Fig. II.13.C.), and in the second graph the microprobe values are replaced by the LA-ICP-MS data for samples analysed twice (Fig. II.13.D). Apparently, there is very little difference between the overall patterns of both these graphs. Even if probably not completely relevant in terms of analytical procedure, the microprobe TiO$_2$ results from the 2010 run, for that particular composition still do have interpretative meaning, and, therefore, will be used for further data processing, along with the rest of the samples not analysed by LA-ICP-MS.

A similar solution is accepted for the magnesia values from the same group of comparisons (Fig. II.13.E.). The 5th c. Mn-decolourised composition samples with lower values of MgO have well correlated EPMA and LA-ICP-MS results, and the microprobe data will be preferred in this case. The 6th c. composition samples, however, demonstrate a considerable spread around the regression line, even if the EPMA 2010 values here are corrected according to the reference measurements. Again, the preference is given to the LA-ICP-MS results for MgO, in the same way as for the previous group of comparisons (cf. Fig. II.12.E.).

The last juxtaposition of the 5th c. and 6th c. composition samples from Dichin presents the EPMA versus the LA-ICP-MS values of manganese (Fig. II.13.F.). The lower analytical quality of MnO results in the EPMA 2010 run was already discussed (see Section II.2.1.3.), and the data used in the comparison are corrected according to the reference measurements. Nevertheless, it does not seem to improve much the figures’ consistency. After the correction, for both the 5th c. and the 6th c. compositions the slopes of the regression lines indicate unrealistically increased values in the
microprobe. The only possibility in such case is to consider the LA-ICP-MS values as true and reliable, and to combine them with the EPMA values of samples not measured by LA-ICP-MS in the 5th c. Mn-decolourised composition group. Such a solution is practically working for the further data processing and interpretation, similarly to the discussion of TiO$_2$ values of the 5th c. composition samples (cf. Fig. II.13.C., D.). Moreover, the reliability of the LA-ICP-MS for manganese is well confirmed by two samples which are the only ones from the present group re-analysed within the EPMA 2013(II) run (Fig. II.13.F. – the two open diamond shapes situated on the line of the ideal data agreement). For these samples the LA-ICP-MS data and the microprobe results are identical, or closely overlapping, confirming that the problem is in the EPMA 2010 run.

Finally, as an example of alumina and lime measured by EPMA and LA-ICP-MS, the samples from the third group of comparisons are plotted (Fig. II.14.), following one of the leading approaches for discrimination of the main mid-1st millennium AD glass groups (cf. Freestone et al. 2008b, Fig. 5). As an effect of the various issues in particular analytical runs of both methods, as discussed in Section II.2.1.3., the overall pictures of both datasets are comparable, but not ideal in terms of precise quantification and thus, in terms of interpretation. It can be concluded that the microprobe results of soda, alumina, and lime are accepted as usable, not forgetting the details in their analytical quality. However, in the attempts for unbiased

---

**Fig. II.14.** Dichin samples (5th c. and 6th c. compositions) – comparison of the EPMA 2010, 2013(II) runs, and the LA-ICP-MS 2010, 2012 runs (uncorrected values for lime from LA-ICP-MS 2012 run).
interpretation of the compositional data, the values of these oxides are not applied as leading criteria for an accurate grouping of the samples in this study.

In conclusion, it can be pointed out that the comparisons between the EPMA and the LA-ICP-MS data obtained from actual samples identified good correlation but also a range of dissimilarities, mostly due to particular problems of performance. The outcomes of the present discussion on the analytical quality and inter-method comparability are summarised in Appendix A.7. This table provides an overview of the results from data evaluation, and of the decisions about the relevance, combinations, corrections, or rejections of the analytical datasets.

II.2.2. Statistical techniques

The application of techniques of statistical analysis, essentially consisting of mathematical approaches to numerical data, is a requirement for present-day archaeological studies which discuss compositional analytical results, likewise the present project. Processing such type of information may employ different statistical methods and to a different extent depending on the particular research goals.

The present project addresses its main objectives through integration of conventional archaeological artefact study and scientific analytical data (see Section I.1.). Both categories of evidence are considered as complementary to each other and being of equal importance. Furthermore, the interpretations of the finds are related to the setting of the historical and archaeological context, and this shifts the research to a more narrative and anthropologically inclined area.

Accordingly, the statistical processing of the compositional data is seen as one of the various tools and no particular emphasis is placed on it. The range of the techniques used in the present study is limited to the more common basics of descriptive univariate statistics (e.g. data parameters such as mean, standard deviation, relative standard deviation, relative difference are used in the quality assessment of the measurements), and certain bivariate methods for graphical visualisation (e.g. scatter-graphs). Some of the primary features of regression analysis (e.g. regression
equation and coefficient of determination) are applied in the comparisons of the EPMA and the LA-ICP-MS datasets in order to explore their relationship, and hence compatibility of the analytical results obtained by both techniques (see Section II.2.1.). However, no attempts are made to employ the same tools for evaluation of the relationship between the concentration ranges of two different oxides in actual glass compositions since the outcome of such calculations depends to a certain extent on the random and unbiased sampling.

The application of multivariate statistical techniques in the studies on ancient glass compositions represents a well-known, however not entirely prevailing practice in present-day research (e.g. Baxter 2015, 106-111; cf. Cagno et al. 2014, Fig. 1). Methods such as hierarchical cluster analysis or principal component analysis (PCA) are often accepted as tools for achieving objective data patterning. However, it is also acknowledged that the use of multivariate statistical methods is not unambiguous (cf. Baxter and Freestone 2006). It does not seem to provide by definition much better answers than what is possible to achieve by certain other approaches.

As explained above, the compositional glass groups attested in the dataset of the present project are identified, characterised, and compared using series of bivariate scatter graphs of pairs of diagnostic oxides, or pairs of their ratios. They were implemented using the basic tools of the Microsoft Excel programme∗. In addition to this preferential application of a descriptive statistical approach, an attempt was made to test the validity of the outlined groups by PCA processing of a selected subset of samples∗∗. Expectedly, the clear separation of some of the main groups in the PCA plots (Fig. II.15.) is in good agreement with the general patterns outlined in the numerous bivariate scatter-graphs (e.g. Appendix A.3.).

However, the positions of a few samples with peculiar chemical makeup within the PCA plot are questionable since they do not seem to correspond to the actual

---

∗ This deliberate choice opposes an extreme viewpoint that there is ‘no longer any excuse’ for the application of Excel in data processing in archaeology (Baxter 2015, 2).

∗∗ The PCA processing of the data from Dicchin, Odartsi, and Serdica was done by James Lankton as part of a bigger project for inter-method comparison of EPMA and LA-ICP-MS techniques (Lankton et al. 2014). The analysis is based on the results for Na₂O, K₂O, MgO, CaO, Al₂O₃, P₂O₅, TiO₂, MnO, Fe₂O₃, and BaO (cf. Lankton et al. 2006 regarding the data treatment).
compositional affiliations of these glasses (Fig. II.15.). For example, samples SER 44 and SER 45 are geochemically linked to the 6th c. composition but likely produced with plant ash based flux (i.e., they demonstrate higher potash and magnesia concentrations; see Section V.2.7). According to the test PCA plot, they may be wrongly associated with the Levantine I samples which in turn feature higher potash concentrations most probably explained by fuel vapour contamination (cf. Appendix A.5.). Apparently, such a nuanced diversity of technological phenomena may not be readily recognised through multivariate statistical data processing, and the theoretical statement that ‘the distances between points on a plot will be a good approximation to the true distances between cases, $d_{ij}$, in p-dimensional space’ (Baxter 2001, 686) is not necessarily correct by definition.

The present example demonstrates that the application of multivariate techniques should be appropriately adjusted in order to attain credible interpretations. However, achieving a suitable model for multivariate analysis of compositional results remains a task far exceeding the objectives of this study. Moreover, the outlined classification of the groups based on integrated criteria proves that meaningful
archaeological observations can lead to efficient preliminary grouping of the materials. Such an approach combined with thorough interpretations of bivariate scatter-graphs of compositional data is able to successfully address the research questions of the present project.

The sections in Chapter II discuss the methodological aspects of the present study, and the approaches employed for addressing its specific research questions. The integration of the results of archaeological artefact research and compositional analysis of the late antique glass vessels from the Lower Danube region is informed by the broader theoretical framework of technological style and chaîne opératoire. In this way, the finds can be considered and grouped according to the characteristics of the glassmaking recipes and compositional modifications, and according to the techniques of vessel manufacture and finishing. Furthermore, an iterated adjustment between archaeological and archaeometric evidence can help to refine the grouping and to outline a persuasive and interpretable pattern within the overall diversity of chemical glass makeups and secondary craft styles. The second part of the Chapter II provides an extensive discussion of the analytical techniques and the evaluation of the data quality which is aimed at achieving a consistent and reliable primary dataset of compositional results.
The detailed discussion of the three vessel glass assemblages studied in this research starts with Chapter III which presents the finds from the Dichin site. The necessary background information about the general archaeological aspects and chronology of the settlement, as well as an overview of the glass assemblage are provided in the beginning of the Chapter. The main part of the text consists of a comprehensive exploration of the artefact characteristics and chemical composition of the vessel fragments. The materials are arranged in five main groups according to the approaches of the integrated classification as discussed in Chapter II. In the end, the variety of the glass compositions attested at Dichin is summarised in an attempt to outline the dynamics of glass supplies to this consumption site.
III.1. Introduction

The vessel glass assemblage from Dichin is the starting point for the present project, and preliminary results were presented earlier (Rehren and Cholakova 2009; Rehren and Cholakova 2010; Rehren and Cholakova 2014). The large-scale fieldwork at this site provided the opportunity to examine stratified and carefully collected glass fragments found during the attentive excavations of well-dated contexts, only moderately affected by later intrusions. The post-exavocation research established a general classification of the entire assemblage based on vessel morpho-typology, functional grouping and manufacturing techniques, and at the same time, related to the chronology of the site (Cholakova 2009a; Cholakova 2009b). These preconditions opened striking perspectives for the scientific analyses it terms of understanding and interpreting the compositional data within the context of vessel usage patterns and significance of various distribution networks. The Dichin site is generally dated to the 5th – 6th c. AD, most probably not surviving into the final two decennia of the 6th c., and belongs to the category of fortified semi-urban settlements. The following sections present an overview of the characteristics and chronology of the site. Furthermore, the main features of the vessel assemblage and its sampling are outlined.

III.1.1. The site

The site is located less than 2 km to the South-West of the modern village of Dichin, municipality of Veliko Tarnovo in Central North Bulgaria. It occupies the top area of a small natural hill, where the original terrain has been intentionally levelled prior to the construction of the late antique settlement (Fig. III.2.A). The hill stands out in a fertile agricultural area within the plain of the Rositsa River, a tributary of the Yantra River leading to the Danube (Fig. III.1.). Such a spot for establishing a fortified site was obviously chosen for its strategic defensive advantages, even though the hill rises to
approximately only ten meters above the surrounding landscape. Dichin is positioned in the vicinity of the Roman town Nicopolis ad Istrum, at about 15 km to the South-West from it (Fig. III.1.). However, during the 5th – 6th c. the character of the former Roman town was significantly changed and it had most probably lost its previous administrative and economic authority over the region (Poulter 1999, 47-48; Poulter 2000). Nevertheless, the establishing of Dichin within the setting of an earlier well-

![Image](image.png)

**Fig. III.2.** Dichin: A. A view to the hill from East; B. geodetic survey plan of the site with the traces of defences and building walls, and the areas of excavation; the North-Western Area F is marked (after Poulter 2007 and Dinchev et al. 2009).
developed Roman infrastructure (including a massive aqueduct bridge crossing the Rositsa River at 0.5 km to the West from the site) is indicative of a certain continuity. A likely explanation for the emergence and initial functions of the fortress is that it was built as a security and controlling point for the river crossing (Dinchev et al. 2009, 329). On the other hand, being situated approximately 50 km to the South of the Lower Danube border of the Empire (Fig. III.1.), the site could hypothetically also have been integrated into the supply system of the frontier (Poulter 2007).

The Dichin site was excavated from 1996 to 2003, within the framework of a joint British-Bulgarian research programme of Nottingham University, the National Institute of Archaeology with Museum – Bulgarian Academy of Sciences, and the Regional Museum of History – Veliko Tarnovo (Dinchev et al. 2009; Poulter 2007). The fieldwork was concentrated in several areas (Fig. III.2.B.), covering not more than 15% of the entire surface of the hill. The team of the National Institute of Archaeology in Sofia worked mainly in the North-Western corner of the fortress (Area F), and the present project includes glass vessel fragments found only at that part of the site.

The earliest phases of occasional occupation on the hill are dated to the Chalcolithic period, the Early Bronze and the Early Iron ages but almost all the prehistoric remains were found in thin layers formed as secondary re-deposition of materials, or just as scattered single finds (Dinchev et al. 2009). No traces of permanent habitation during Roman times were found within the excavated areas of the site.

The foundation of the late antique fortified settlement is dated to the early years of the reign of Theodosius II (408-450). A massive defensive wall built ca AD 410 surrounds an area of approximately 1.1 ha, following the edge of the levelled plateau (Fig. III.2.B.). Additionally, an external wall (proteichisma) protected the less steep Western and Southern slopes of the hill. Both the main curtain and the proteichisma were carefully constructed with stone blocks, brick layers (opus mixtum), and mortar. The remains of two gates, four towers, and a few staircases leading to the platform of

---

* The discussion of the site chronology and interpretation in the present section follows the account presented in Dinchev et al. (2009).
the defensive walls were excavated. A circular corner tower, a gate, and a staircase were found in Area F (Fig. III.3.). The features of the buildings within the fortified space considerably differ from the construction techniques of the fortifications. A certain planning of the streets and houses is evident from the general layout of the site but the overall pattern is rather dense, with not much open space along the inner side of the curtain. Buildings were constructed of stone and mud-bricks, only occasionally with mortar and most often with earth bonding. Most of the houses had an upper floor, glazed windows; roof tiles were used for building covering. A particular area within the Western part of the fortress (Area E) was occupied by series of store rooms and granaries (horrea). The archaeological materials and the character of the settlement indicate that the inhabitants of Dichin during the 5th c. period were not a regular army unit but civilian population involved in farming which most probably also had served certain military duties (Poulter 2013, 377). This is in line with historical evidence about the organisation of the late antique army which included various categories of regular troops, militarised civilian population, and not last – numerous groups of foederati (Dinchev 2006, 39-44; see Section I.2.1.). However, a tentative interpretation of Dichin as a fort of a Gothic community which acted as a garrison of foederati in this borderline area (The Transition to Late Antiquity; Smith 2011) remains quite intriguing but impossible to prove due to the complexity of the processes of unification within the late antique provincial society.

The settlement survived within this spatial and social configuration almost until the end of the 5th c. An important disagreement regarding the end of this first period of the site exists between the results of the British and Bulgarian teams. According to the interpretation of the British archaeologists Dichin was destroyed by a hostile attack and fire at the end of the 5th c., or at a certain moment within the approximate timespan AD 474-518 (Poulter 2007; Guest 2007). The reconstruction of the settlement took place immediately or shortly after this event and the site existed approximately until AD 575-600 according to the numismatic evidence (Guest 2007, 306; the results of the British team are in preparation for their final publication).

* ‘...material cultures and identities might have been more fluid than the Roman and German labels suggest.’ (Guest 2007, 301).

** ‘...it must have occurred at the very end of the 5th century AD.’ (The Transition to Late Antiquity).
The North-Western Area F provided somewhat different and more detailed evidence about the chronology of the settlement. According to Dinchev and co-authors (2009) the 5th century period of the site consists of two phases. The initial construction
of the buildings in Area F is dated to ca AD 410. Two buildings were entirely excavated to the West from the street leading to the Northern gate, and remains of two more buildings were partially unearthed on the Eastern side of the street (Fig. III.3.A.). These buildings were destroyed by a devastating fire ca AD 470, probably as a result of one of the latest Huns attack in the province of Moesia Inferior (see Section I.2.1.) which certainly has had affected the whole settlement and not only the North-Western Area F. This event marks the end of the first phase of the first period of Dichin. The buildings were reconstructed shortly after the fire. Generally, the architectural planning and building techniques remained the same, but with certain changes – separation of new spaces (Fig. III.3.B.), and considerably higher situated ground floor surfaces, as a result of a new levelling of the terrain. This second phase of the first period ended at about AD 490, again with a massive destruction which could be related to the last raids of Goths in Moesia Inferior (see Section I.2.1.). The close similarity in the planning of the buildings, their functions, and the materials found in these contexts allows to consider both these phases as two stages of the same period of the site, with no change of the inhabitants of the fortress.

Based on the analysis of numismatic evidence, the beginning of the second period in the North-Western area is dated to ca AD 540, i.e. it is supposed that the settlement remained uninhabited for almost half a century. The life in Dichin resumed probably as an episode of the campaigns of Justinian I for stabilisation of the Lower Danube provinces (see Section I.2.1.). However, the new occupants did not maintain many of the features of the 5th c. fortress. The buildings in Area F had new planning; the Northern gate was closed and was not in use anymore (Fig. III.3.C.). The new levelling of the terrain in the 6th c. formed new and higher situated surfaces of the floors, some of the existing walls were re-used but also new buildings were constructed using poorer materials and techniques compared to the 5th c. practices. This is seen as evidence of a lower degree of economic, everyday-life and cultural standards of the 6th c. community which lived in Dichin. Lower standards of consumption needs are indicated by the reduced ranges and quality of almost all groups of finds; not many ceramic imports (tableware or amphorae) reached the site in the 6th c. Apparently, considerable changes did take place during the second period.
of the site but defining them in the aspect of ethnicity is impossible*. It is also infeasible to specify potential military functions of this civil population in the organisation of the 6th c. frontier defence of Moesia Inferior. The end of the second period of Dichin is marked by another fire and destruction layers. The latest coins from the site are dated to AD 575/6 (Justin II and Sophia) and ca AD 580 (probably Tiberius II Constantine?) which suggests that the final devastation of the settlement happened ca AD 580, possibly caused by some of the numerous attacks of Slavs and Avars, the most active raiders in the Lower Danube region towards the end of the 6th c. (see Section I.2.1.).

No remains of later occupation on the hill were found. The site suffered post-medieval stone-robbing which destroyed large parts of the walls. Regardless of this, most of the stratigraphy and the contexts remained well-preserved, and the trenches from stone-robbing allowed the British team to create a tentative but still very clear and indicative plan of the settlement (Fig. III.2.B.).

As mentioned earlier, the present research takes into account the archaeological artefact study of the entire vessel glass assemblage from Dichin (Cholakova 2009b). However, only the finds from the North-Western Area F were available for sampling and compositional analysis (see Section I.1.). Therefore, the periodisation and dates suggested by the results of the Bulgarian team are acknowledged as valid for the current project; a discussion on the differences between the chronological schemes of both fieldwork partners is beyond the remit of this work.

Nevertheless, it should be pointed out that the integrated interpretation of the vessel morpho-typology and glass chemical makeup in relation to the accepted archaeological site periodisation and tight dating offers notable advantages for the present study. Certain subtle and gradual changes of the 5th c. pattern of glass groups are recognised between its two phases, while an abrupt switch to the composition of the 6th c. corroborates the longer break (i.e. the sharp separation and chronological hiatus) between the two main periods of the site (see Section III.2.6.).

*‘Marginal provincial population in the 6th c. Balkans’ is the suggested neutral definition by V. Dinchev (Dinchev et al. 2009, 330).
Finally, a short comment on evidence of local small scale glass working in Dichin is necessary. No direct traces of secondary glass manufacture were found within the excavated areas. A single chunk of raw glass (see Fig. VI.1.A. in Section VI.1.1.1.; Cholakova 2009b, 282-283) and possible glass blowing waste fragments (see Section III.2.3.) imply that some, perhaps limited production activities may have taken place in the settlement, most probably during its first period. However, such an interpretation remains unverifiable. Strictly speaking, one can state that the population of the 5th c. settlement must have been familiar with the raw materials used in the secondary glass workshops, while any further assumption would be an overstatement.

III.1.2. The glass vessel assemblage and sampling

A significant amount of glass fragments was excavated at Dichin, and among them the overall number of the identifiable and informative pieces is ca 270*. They were all taken into account in the archaeological study of the assemblage; 119 of them were selected and already published in an illustrated catalogue (Cholakova 2009b). The finds from Area F comprise approximately one third of the catalogue numbers.

As mentioned earlier, the analytical work of the present project includes only the finds excavated in the North-Western Area F of Dichin. All the Area F fragments from the catalogue were sampled, except a single burnt neck of a flask. Additionally, in an attempt to ensure the representative character of the results, some of the fragments found at Area F (but not included in the published catalogue) were also analysed. In this way, the overall number of the studied samples is 80, measured by EPMA and LA-ICP-MS within seven analytical runs in total (see Section II.2.1.2.; Table II.1.). Being aware that some of them may belong to one and the same vessel it can be stated that the chemical dataset from Dichin represents at least 70 particular vessels** and 3 window glass pieces. The range of vessel shapes includes various groups of

---

* The finds from Dichin are part of the collection of the Regional Museum of History in Veliko Tarnovo.
** This is a conservative estimation. Due to the fragmented state of the vessels it was not always possible to decide whether the pieces come from one and the same vessel or from two or more similar vessels. Chemical data confirmed several cases of ‘single batch’ episodes (see Sections II.1.2., III.2.1., and III.2.4., Fig. III.5.) but still evaluating the exact number of vessels coming from a ‘single batch’ was not always possible.
tableware (mostly drinking vessels but also bowls and jugs) and oil lamps. The archaeological grouping of the entire assemblage was already completed by the time when the analytical research began. Therefore, the selection of fragments for analysis was aimed at a comprehensive study of all defined archaeological groups and nearly total population sampling.

The analysed glass from Area F covers ca 30% of all the identifiable vessel pieces from the site, and thus it is believed to be generally representative for the whole Dichin assemblage. However, certain details also need to be taken into account. The number of the analysed samples in each group does not necessarily reflect the actual percentage of the groups within the entire assemblage. For example, stemmed goblets Isings 111 comprise approximately one third of all Dichin glass but they are represented by only 15 samples in this dataset. Furthermore, certain specific groups such as vessel handles and intentionally coloured glasses (cobalt dark-blue, light-blue, and dark-green – Cholakova 2009b) are not studied here, since all relevant fragments come from the areas excavated by the British team.

The sampling of the groups present in the Area F sub-assemblage was performed following the initial archaeological classification in the published catalogue. The expectation was that the groups would differ not only in terms of macroscopic features but also in their chemical makeup (e.g. bowls with engraved decoration, vessels with decoration of blue trails, plain bowls with fire-rounded rims, cups with cracked-off rims, etc.). The refinement of this grouping through integration of the compositional results demonstrated the usefulness of the iterative method of repeated adjusting between archaeological and chemical data interpretation (as described by French scholars – va-et-vient way of research, Foy et al. 2003, 80; see Section II.1.2.). Accordingly, in the final classification presented here some of these earlier archaeologically-defined categories are incorporated into a single bigger unit based on their compositional uniformity (see Section III.2.4.).
III.2. Groups in the Dichin assemblage

The entire assemblage from Dichin presents a wide range of shapes, techniques of decoration, and glass colour tints. However, the vessel fragments from Area F are all free blown (possibly with only two exceptions – a small base fragment G 84, Fig. III.18., and a rim sherd G 52, Fig. III.17.), and, apart from its occasional use in ornamental details, there are no examples of strongly coloured glass in this sub-assemblage. Vessel finishing and decoration are made by both the cold-working and the hot-working techniques. The first include wheel-engraving and abrasion, free-hand engraving, rim polishing, whereas the second consist of applied trails – marvered, semi-marvered, or left standing in relief (made of dark-blue glass or self-coloured), applied blobs of dark-blue glass; tooled folds, fire-rounded rims. The glass hues vary from intentionally decolourised or modified into saturated olive-amber, to the various tints of the natural blue-green colour depending on the concentration of mineral impurities in the glassmaking sands. Interestingly, glasses with no visually recognisable colour alterations seem to constitute the smaller part of the assemblage and the majority of the fragments are made of glass containing certain amounts of colour-modifying additives.

The sections below provide a detailed discussion of the groups in the studied part of the Dichin site assemblage. As explained above, this classification results from a combined study of the archaeological traits and chemical makeup of the finds (see Section II.1.2). Five main groups are defined in Dichin and a few outliers are discussed separately in the final paragraphs of Section III.2. In certain cases, when analogies with the Odartsi and Serdica glass are necessary, the text refers to Section IV.2. and Section V.2., respectively.
III.2.1. Engraved bowls – aqua-blue glass (Levantine I composition)

This is a small but distinctive group of seven samples, quite consistent in terms of vessel characteristics and chemical makeup (Appendix B.2.1.). Morphologically they belong to Isings 116 type* – a shallow or deeper bowl with cracked-off and polished rim, manufactured without a pontil rod (Fig. III.4.). Similar techniques of cold glass-working (wheel-engraving, abrasion, wheel-cutting) were used for the decoration of the vessels; a diagnostic element of the type is a wide groove below the rim. One of

* Sample G 32 comes from a small undiagnostic wall fragment which may well be a piece of Isings 116 bowl. At first the fragment was added to this group because of the specific visual appearance of the aqua-blue glass; later the analytical results confirmed its identification.


<table>
<thead>
<tr>
<th></th>
<th>SiO₂</th>
<th>Na₂O</th>
<th>Al₂O₃</th>
<th>CaO</th>
<th>K₂O</th>
<th>MgO</th>
<th>P₂O₅</th>
<th>Fe₂O₃</th>
<th>TiO₂</th>
<th>MnO</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>69.8</td>
<td>14.8</td>
<td>2.95</td>
<td>9.05</td>
<td>0.95</td>
<td>0.53</td>
<td>1323</td>
<td>0.35</td>
<td>0.07</td>
<td>0.05</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1.00</td>
<td></td>
<td></td>
<td>0.47</td>
<td></td>
<td>0.14</td>
</tr>
</tbody>
</table>

Table III.1. Average chemical composition of the Levantine I glass samples from Dichin (n=7; all oxides in wt%; only P₂O₅ in ppm). The high-manganese sub-group has nearly threefold elevated MnO concentrations than the low-MnO sub-group and also higher potash and iron oxide (highlighted). See Appendix B.2.1 for detailed data.

the bowls (G 25) has a Greek inscription reconstructed as ΠΠΕ ΖΗΣΗΣ and cruciform decoration on the bottom. Close analogies of these Dichin finds are known from the East Mediterranean, the Balkans, and the Northern Black Sea region (Iliffe 1934, Fig. 17; Harden 1949, Fig. 3; Antonaras 2010b, Fig. 8.6.; Shepherd 1999, n240; Kunina 1997, n433), even though the distribution of this popular type is not restricted to the Eastern parts of the Late Roman world only (e.g. Price and Cottam 1998, 124-126). All the fragments come from destruction contexts of the first phase of the first period of Dichin, ca. AD 410-470, which is a later date compared to the known parallels commonly defined as 4th c. finds. At the same time, it had been previously suggested that Isings 116 bowls had a longer production tradition in the Eastern regions of the Empire (Dussart 1998, 4.25, 4.31). Fragments of a nearly identical inscribed bowl were found in a well-dated 5th c. deposit in Nicopolis ad Istrum (P. Vladkova, pers. comm.), making unlikely the interpretation of the finds from Dichin as heirlooms incidentally preserved in later contexts. They rather seem to be an example of 5th c. import to the Lower Danube of finished vessels originally manufactured in the Eastern Mediterranean (possibly Syria).

In terms of chemical composition, with its typically high alumina and lime levels but lower soda concentrations (Table III.1.), this group unequivocally belongs to the Levantine I glass as defined by Freestone and co-authors (2000; 2002a) and broadly matches Foy and co-authors’ Série 3.3. (Foy et al. 2003). The sand used for its making is relatively uncontaminated with mineral impurities, probably originating from the Levantine coast (‘Belus river’ type sand), which gives less than 0.5 wt% iron oxide and low levels of some trace oxides (TiO₂, ZrO₂ etc.) in the glass. The Levantine I glass primary production is proved for Apollonia-Arsuf tank furnaces in Northern Israel from the 6th – 7th c. AD (Freestone et al. 2008b), and this compositional group is dominant...
Fig. III.5. Levantine I glass samples from Dichin: scatter-graph of the individual EPMA measurements on each sample of manganese and potash levels. A low-MnO sub-group (G 25, G 31, G 27) and a high-MnO sub-group (G 26, G 29, G 30, G 32) are outlined. The compositional overlap of certain samples suggests they come from one and the same vessel or from different vessels produced as a ‘single batch’ episode.

within the immediate region of its primary melting (e.g. Rehren et al. 2010). However, it is suggested that Levantine I glass was not so widespread in the Western part of the late antique world (e.g. Foster and Jackson 2009; Gallo et al. 2014).

Visual comparison between the studied fragments and the information about their context suggest that probably some of the pieces belong to one and the same vessels (e.g. G 25 & G 31, G 26 & G 29). Chemically all seven samples, possibly belonging to only five vessels, are very similar. The close overlap between the series of individual EPMA measurements on different fragments (Fig. III.5.) indicates that they could come from a single workshop or even from a single production episode/melting event; hence, the set of finished vessels likely formed a one-off acquisition to the settlement (Rehren and Cholakova 2014).

However, a closer inspection of the data distinguishes two sub-groups on the basis of their manganese content (Table III.1., Fig. III.5.). Three samples have low-MnO levels approximately corresponding to the background MnO concentrations in glassmaking sands (Brems and Degryse 2014; ca 200 ppm MnO as natural level in Levantine glass – Freestone et al. 2015a, 51), which means that the glass was produced
with no additional source of manganese in the batch. The remaining four samples demonstrate elevated MnO content which is not high enough to affect the glass colour but most probably indicates mixed re-melting of this naturally-coloured Levantine I composition and (a certain kind of?) Mn-containing glass. The four high-MnO samples have also slightly higher iron oxide and potash concentrations than the low-MnO sub-group (Table III.1.). These features are consistent with the interpretation of recycling since iron contamination, from the ceramic crucible fabric or blowing iron, is a probable effect of repeated re-use of glass (Jackson and Paynter 2015), while increased potash may result from fuel ash/ vapour contamination (Paynter 2008, Rehren et al. 2010).

Interestingly, the separation of low-MnO and high-MnO sub-groups corresponds to certain differences in the quality of vessel manufacture. The finer bowl with elaborate lettered decoration (G 25) is made of unadulterated glass. The thick-walled bowl with irregular rim-finishing and slightly decentred decoration (G 26) is made of a batch of likely mixed glass with signs of recycling∗. This compositional and archaeological sub-division may offer a fascinating, although only hypothetical insight into the organisation of vessel glass manufacture. Possibly, in this particular case, a certain awareness and intentional selection of raw materials (i.e. fresh raw glass and/or recycled cullet) existed according to the level of skilfulness of the glass-blowers within a single workshop or between closely related workshops with different degrees of craftsmanship.

Finally, the consistently high potash concentrations (0.95-1.00 wt%) in this group deserve some comments since they differentiate the Levantine I samples from the rest of the studied set (Appendix A.5.). Potash is frequently found in Levantine I composition at levels of about 1 wt % and often quite higher (e.g. Gallo et al. 2014, AQ/2a, Maltoni et al. 2015, CL2), and this, in correlation with phosphate is interpreted as a result of fuel ash contamination (Tal et al. 2008, Rehren et al. 2010). The samples from Dichin have relatively high P₂O₅ values (ca 1300 ppm) but these are not correlated with their elevated potash. The comparison with the unworked chunks of

∗ The levels of Sb₂O₃, CuO, PbO in the Levantine I glass samples may also be indicative but their absolute concentrations are quite low and are not discussed here (see Appendix B.2.1).
Levantine I composition from Serdica (see Section V.2.1; Fig. V.7.B.) suggests that the potash enrichment of glass is likely related to the re-melting at the stage of secondary working. Further juxtapositions, which are beyond the scope of the present work, are needed to clarify whether the distinctively increased K$_2$O in Levantine I glass results from a particular technology of prolonged batch heating in the secondary glass workshops, multiple cycles of cullet recycling, specifics of the fuel used, some peculiar furnace construction (Rehren et al. 2010), or combination(s) of several factors. However, in the case of the Dichin assemblage, this special compositional trait of the Levantine I samples is tentatively seen as indirect evidence of the overseas origin of these Isings 116 bowls themselves (as finished objects and not only in terms of the raw glass used for their manufacture), since it is not recognised in any of the other samples in the studied set.

III.2.2. Bowls and beakers with fire-rounded rims – saturated-green glass (HIT composition)

Likewise the previous group, the fragments made of saturated-green glass form a very tight and easily recognisable group within the Dichin assemblage. The sub-assemblage of finds from Area F provides very few examples of this type (hence, only six samples were studied here, Appendix B.2.3), probably due to the specifics of the site stratigraphy. No reconstructions of entire shapes were possible because of the high degree of fragmentation. However, the study of all saturated-green vessels from Dichin shows that these are mostly bowls and beakers (lamps?) with base pontil marks, carefully shaped fire-rounded and then lightly polished rims, showing a variety of fine rim-section modelling (Fig. III.6.; Rehren and Cholakova 2010, Fig. 2). No additional decoration was found on the excavated fragments.

The contrasting techniques used in such an elaborated multi-stage vessel finishing (i.e. the application of both hot and cold glass working), as well as the attentive pontil scar removal indicate the advanced workmanship of a particular craft tradition in the secondary glass manufacture. At the same time, the vessel shapes should not be seen as exceptional or belonging to a certain specialised range of elite
Fig. III.6. Dichin – fragments of bowls and beakers with fire-rounded rims made of HIT glass composition, ca AD 470-490 (after Cholakova 2009b; Rehren and Cholakova 2010). The micro-photograph (bottom right) illustrates the distinct glass tint of this chemical makeup resulting from the natural impurities (i.e. elevated Fe$_2$O$_3$) in the glassmaking sand.

production. Morphological parallels of the bowls are known from various regions, e.g. Egypt, Carthage, Iberian Peninsula (Harden 1936, n28, n345; Fünfschilling 2009, Fig. 3.12; Cruz 2014, Fig. 7.2.4.), including some examples from Dichin which have very similar rims but are made of different glass and are often decorated (see Section III.2.4.; Cholakova 2009b, Tabl. V, Tabl. VII). Therefore, in terms of morpho-typology these vessels should be placed in a wider tradition of utilitarian vessel manufacture, and identifying their exact analogies does not seem feasible at the present state of research.

The fragments of saturated-green glass were all found in 5$^{th}$ c. contexts of Dichin. The evidence from Area F and a comparison with the other excavated areas suggest that this group is typical mostly for the second phase of the first site period (ca AD 470-490). Such a tight dating corroborates the hypothesis that this is a case of a particular acquisition to the site but not an example of continuous commercial deliveries. As mentioned earlier, the group is quantitatively small and very coherent in composition and craft-style characteristics. The identification of a ‘single batch’ pair of samples (G 1 and G 2 – Rehren and Cholakova 2010, Fig. 4b) is consistent with the
assumption of one-off supply. The origin of the vessels may be tentatively interpreted as an inter-regional import to the Lower Danube but defining the location of the secondary workshop which has produced them as finished objects remains problematic.

The saturated-green glass was recognised as a distinct chemical group dubbed HIT (High Iron and Titania) for the first time among the finds from Dichin (Rehren and Cholakova 2010). Basically, it has all the diagnostic features of the well-known HIMT composition (e.g. elevated Fe$_2$O$_3$, TiO$_2$, MgO, Al$_2$O$_3$ and relatively low CaO content) except the missing high concentration of manganese (approximately 0.05 wt% MnO in

<table>
<thead>
<tr>
<th>SiO$_2$</th>
<th>Na$_2$O</th>
<th>Al$_2$O$_3$</th>
<th>CaO</th>
<th>K$_2$O</th>
<th>MgO</th>
<th>P$_2$O$_5$</th>
<th>Fe$_2$O$_3$</th>
<th>TiO$_2$</th>
<th>MnO</th>
</tr>
</thead>
<tbody>
<tr>
<td>67.9</td>
<td>18.2</td>
<td>3.13</td>
<td>5.09</td>
<td>0.39</td>
<td>1.04</td>
<td>461</td>
<td>1.55</td>
<td>0.58</td>
<td>0.05</td>
</tr>
</tbody>
</table>

Table III.2. Average chemical composition of the HIT glass samples from Dichin (n=6; all oxides in wt%; only P$_2$O$_5$ in ppm). Sample G 60 with increased levels of oxides indicative of glass recycling is excluded from the averaging of MnO presented here. See Appendix B.2.3 for detailed data.

Fig. III.7. Comparison of the MnO levels in the HIT samples (Dichin only) and the HIMT samples (Dichin, Odartsi, Serdica). The control over the balance of Fe$_2$O$_3$–MnO absolute concentrations and oxidation states determines the glass colour, and is a deliberate technological choice as part of the glassmaking recipes. The HIMT cluster of samples consists of two sub-groups which differ in their Fe$_2$O$_3$ levels (see Section III.2.3.)
the Dichin samples; Table III.2.). Therefore, the HIT composition is considered as a variety of the HIMT glass which lacks the recipe-linked element of intentionally added MnO as a colour modifier (Fig. III.7.). It is the high iron oxide that gives the distinct saturated green colour of the HIT glass. The trace oxide pattern of the HIT samples (e.g. increased ZrO$_2$ and Cr$_2$O$_3$ values) confirms the link to the particular sands used for the HIMT production, most probably with an Egyptian/ North Sinai provenance (see Section III.2.3.; for details of the BaO levels see Fig. IV.11.B. in Section IV.2.2.).

Only one of the analysed samples (G 61) demonstrates enrichment of base metals used as colorants which are interpreted as recycling indicators when present in low concentrations but above the natural threshold levels (Cu, Zn, Pb). Another sample (G 60) differs by its content of MnO, which is nearly double compared to the rest of the group, and has also slightly higher levels of colorants (cf. Fig. III.9.C.; see Appendix B.2.3.). Nevertheless, the group should not be seen as an output of overly recycled raw material processing. It is plausible to expect that the vessel manufacturers were well supplied with fresh raw HIT glass but the overall number of analysed samples is too small for a more conclusive statement.

The HIT samples from Dichin are quite peculiar, even though recent analytical studies show that they are not completely exceptional*. Late antique glass with elevated iron oxide and titania but low MnO content has been used for mosaic tesserae production (e.g. Schibille et al. 2012a, sample SAP-038 coloured with CuO), for trail decoration (Conte et al. 2014, sample BT39a coloured with CoO), and for vessel manufacture (Conte et al. 2014, samples BT41 and BT45; Maltoni et al. 2015, sample D26; Rosenow and Rehren pers. comm., two samples – all these fragments are Co-coloured). It could have been a reasonable choice to produce dark-coloured glass using the HIT base composition but further data is needed to identify whether the colouring was part of the primary melting recipe (i.e. as a centralised large-scale production) or it took place at the stage of secondary re-working (i.e. as multiple occasional colour modifications in various local settings). Only two naturally-coloured vessel HIT examples outside Dichin are known so far: one comes from Cyprus and is

* Unfortunately, some of these publications tend to ignore the archaeological aspect of the materials they present; hence it is hard to make a meaningful comparison with the Dichin finds.
interpreted as an import of finished production from Egypt (Ceglia et al. 2015, sample ID821), and the second was found in Armant in Upper Egypt (Rosenow and Rehren pers. comm.).

III.2.3. Beakers and bowls with cracked-off rims – yellow to dark-olive/ brown glass (HIMT composition)

Vessels made of yellow-brownish to olive-green glass are one of the most typical late antique groups in the Mediterranean and beyond, and their presence in the Dichin assemblage is quite expected. It seems that they were relatively popular at this site, and the number of fragments from Area F analysed here is sixteen (Appendix B.2.2.). No entire shape reconstructions were possible. However, the overall typological range in this group is identified based on certain distinct morphological and manufacturing features and comparisons to well-known parallels.

The group consist mostly of beakers with outsplayed rims and straight walls (Fig. III.8., G 13), broadly matching Isings 106b-c forms. Their bases are plain and slightly concave, with a distinct constriction of the walls just above the bottom (Fig. III.8., G 16, G 37). Bowls with identical rims and rounded bases are fewer – their deeper varieties Isings 96a/107 are known from Serdica (see Section V.2.2), and shallower varieties Isings 96a/116 are found at Dichin (Fig. III.8., G 12, G 14). A base fragment with low ring and pushed-in bottom resembles Isings 109c beakers (cf. Foy 1995, Form 14), and another thick-walled base fragment has a central kick and pontil mark (Fig. III.8., G 15, G 39). Interestingly, the Dichin assemblage provides some pieces which could be hypothetically recognised as glass blowing waste or malformed fragments (Fig. III.8., G 11, G 17). The tentative interpretation of G 17 as a lid-moil is based on the size (too small for a jug neck) and mostly on the significant contamination of the glass with particles from the blowing iron. Although it is not definitely impossible to reconstruct G 11 as a wall of an indented vessel, the lack of any similar combination of indentions and applied blue blobs suggests that it may be a beaker fragment deformed during the annealing. In fact, examples of identified glass working waste (as opposed to unworked chunks) of this particular composition deserve mentioning since they are rare finds (cf.
Fig. III.8. Dichin – fragments of beakers and bowls with cracked-off rims made of HIMT glass composition, ca AD 410-470 (after Cholakova 2009b; Rehren and Cholakova 2010). The micro-photograph (bottom right) illustrates the distinct glass tint of this chemical makeup resulting from the natural sand impurities (i.e. elevated Fe₂O₃) and the added colour modifier (i.e. elevated MnO) in the glass melt. Note the contaminated glass of G17 containing sizable bits from the blowing iron.

the list in Nenna 2014) and only recently published finds (Maltoni et al. 2015; Rehren and Brüggler 2015).
In general, the Dichin vessels that belong to this group are produced without the use of pontil rod (except G 39); their rims are cracked-off and slightly smoothed, but often left unworked and rough. Decoration consists of quite typical applied blobs of dark-blue glass, or thick trails forming pattern of linked rhombuses (Cholakova 2009b, Tabl. III), and occasionally, very fine wheel-engraved lines (cf. G 13). The overall quality of their manufacture is good although not of a particularly high level.

Numerous analogies of this distinct group are found across the late antique world. Remarkably similar beakers are known from sites at the Northern and Eastern Black Sea coasts (Sorokina 1971; Golofast 2009, Fig. 1; Baghatura-Kner 2009), in the Middle Danube region (Barkóczi 1988, Taf. XIV), and also in Egypt and Tunisia (Faiers 2013, 38; Foy et al. 2003, VRR 376). Some of the well-studied sets come from Southern France where this group forms up to 80% of the entire glass assemblages in the 5th c. contexts (Foy 1995, 199, Pl. 9-10). Examples of such glasses are also found in the Balkans (e.g. Ružić, 1994, 45-47), including the immediate region of Dichin, and thus their local manufacture was suggested (e.g. Gomolka 1979, 147-148; Nicopolis ad Istrum finds in Shepherd 1999, 372).

All the fragments excavated in datable contexts in Area F belong to the 5th c. period of the site and the overwhelming majority of them are dated to the first phase, ca AD 410-470. Three pieces (G 12, G 14, G 35) were unearthed in layers formed shortly before the construction of the fortress, confirming that these glasses were among the earliest in use at Dichin. Interestingly, two of them seem to belong to a ‘single batch’ production episode (G 12 and G 14 – Rehren and Cholakova 2010, Fig. 4), most probably acquired as a single delivery by the inhabitants of the site. The regional origin of the vessels in this group (or most of them) is quite possible, given their abundance in the Lower Danube, the relatively crude and unsophisticated manufacturing, as well as the possible blowing waste fragments.

To sum up the macroscopic archaeological characteristics of this group – in Dichin, as well as in Odartsi and Serdica (see Sections IV.2.1. and V.2.2.) it consists mostly of yellow to dark-olive/brown tall beakers and, to a lesser extent bowls, with outplayed cracked-off rims, manufactured without pontil, and decorated occasionally
with blue blobs and shallow incised lines. The date of the group is 5th c., being probably more typical for the earlier decennia of the century.

This group is compositionally consistent with the well-known HIMT glass makeup, and demonstrates the same correlation of date, vessel morphology/decoration and chemical type as observed in Southern France (Foy et al. 2003, Groupe archéologique B and Groupe de composition 1). The HIMT (High Iron, Manganese, and Titania) primary production group is characterised by elevated eponymous oxides and overall higher concentrations of alumina, magnesia, soda, and oxides deriving from heavy minerals in the glassmaking sands (ZrO$_2$, Cr$_2$O$_3$, certain REEs). It seems that the visual properties and chemical/technical characterisation of the yellow to olive-green HIMT composition represent an opposite to the pale blue Levantine I glass. The sands used for this production have complex nature and probably not straightforward geological explanation (Freestone et al. 2005), as a contrast to the ‘pure’ Belus-type Levantine sand. HIMT glass was defined by I. Freestone (1994) and confirmed in numerous assemblages in the Mediterranean (e.g. Mirti et al. 1993; Foy et al. 2003; Freestone et al. 2002a) and beyond (Foster and Jackson 2009). No direct evidence of the production area of the primary HIMT glass was found so far, but based on geochemical reasoning an Egyptian/ North Sinai origin is suggested (Freestone et al. 2005, Nenna 2014).

The brief discussion of the HIMT composition in the Lower Danube region (Table III.3.) presented below takes into account the entire dataset of the current project (i.e. all the HIMT samples from Dichin, Odartsi, Serdica and Samokov). The typical chemical composition of the studied materials demonstrates, apart from the

<table>
<thead>
<tr>
<th>SiO$_2$</th>
<th>Na$_2$O</th>
<th>Al$_2$O$_3$</th>
<th>CaO</th>
<th>K$_2$O</th>
<th>MgO</th>
<th>P$_2$O$_5$</th>
<th>Fe$_2$O$_3$</th>
<th>TiO$_2$</th>
<th>MnO</th>
</tr>
</thead>
<tbody>
<tr>
<td>65.3</td>
<td>17.4</td>
<td>3.17</td>
<td>5.70</td>
<td>0.41</td>
<td>1.10</td>
<td>1425</td>
<td>3.36</td>
<td>0.51</td>
<td>1.78</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2.98</td>
<td></td>
<td></td>
<td></td>
<td>668</td>
<td>1.84</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table III.3. Average chemical composition of all the HIMT glass samples in the present dataset (n=32; all oxides in wt%; only P$_2$O$_5$ in ppm). The sub-group with nearly twice lower iron oxide content (formally labelled ‘HIMTb’) features also slightly lower alumina, somewhat higher manganese, and considerably lower phosphate (highlighted). Sample SER 35(1) is excluded from the averaging of P$_2$O$_5$ because of its extreme value. See Appendix B.2.2. for detailed data.
eponymous oxides, also the distinctly high values for alumina and magnesia. Lime is relatively low, as expected for the HIMT glass, and titania is at the extreme side of the published HIMT range. The samples in the present dataset do not confirm a specifically soda-rich recipe of this group supposed elsewhere (Freestone et al. 2005; Nenna 2014), even though the existence of a clearly separated ‘low-soda’ variety, as initially suggested in the preliminary publication, cannot be recognised any longer (Rehren and Cholakova 2010). Only five samples in the present dataset feature such low soda concentrations (SER 46, G 12, G 14, G 17, G 36; cf. Appendix B.2.2).

HIMT glass is subject of a steady research interest and an attempt is made here to situate the materials from the Lower Danube in the context of recent analytical works. The accumulation of new compositional data from around the Mediterranean allows a separation of two sub-groups within the general HIMT makeup*. Two distinct ratios of titania and iron oxide are identified in the dataset from Aquileia (Gallo et al. 2014). The same separation is outlined in glass found at Bubastis in Egypt (Rosenow and Rehren 2014, Fig. 8), and confirmed in another site assemblage from Italy (Maltoni et al. 2015). Two sub-groups, labelled as ‘a’ and ‘b’ are discussed in both papers presenting data from Italy, with ‘a’ having the highest values for iron oxide, titania, and manganese. Both sub-groups are recently reported also in glass assemblages from Cyprus (Ceglia et al. 2015), with the explanation that the variable iron content is due to internal heterogeneity of the sand deposits**.

The analyses of the HIMT samples from the Lower Danube support this differentiation, and provide more detailed evidence of the sub-group with extreme values of iron oxide. ‘HIMTa’ and ‘HIMTb’ are used here as formal labels, following the model of Gallo et al. (2014) and Maltoni et al. (2015), to denote both versions of HIMT glass (Table III.3.). The difference in \( \text{Fe}_2\text{O}_3 \) absolute content of both sub-groups is most easily seen. At the same time, differences in \( \text{Fe}_2\text{O}_3–\text{Al}_2\text{O}_3 \) ratios are also present, with stronger correlation of both oxides only in ‘HIMTb’ glass (Fig. III.9.A.; cf. Freestone et al.

---

* This grouping is not equivalent to the differentiation of ‘HIMT 1’ (‘strong’) and ‘HIMT 2’ (‘weak’) introduced for the materials from Britain (Foster and Jackson 2009; Jackson and Foster 2014). Only ‘HIMT 1’ from Britain is considered here as part of this distinct group since ‘HIMT 1’ and ‘HIMT 2’ are fundamentally different in their geochemistry, as pointed out by Freestone (2014).

** Remarkably, the publication of the Cyprus glass fails to maintain the consistent ‘a’ and ‘b’ labelling of both sub-groups introduced by the papers on the Italian data, i.e. for Cyprus both labels are swapped.
HIMT and HIT glass samples from the present dataset: the sub-groups ‘HIMTa’ and ‘HIMTb’ (and geochemically joint to it HIT glass) separation is based on sand-deriving oxides (A., B.), while evidence of glass recycling seem to be equally minimal (C.).

Fig. III.9. HIMT and HIT glass samples from the present dataset: the sub-groups ‘HIMTa’ and ‘HIMTb’ (and geochemically joint to it HIT glass) separation is based on sand-deriving oxides (A., B.), while evidence of glass recycling seem to be equally minimal (C.).
2005, Fig. 2.). An identical trend for a divergent, weaker or even no correlation of \( \text{Fe}_2\text{O}_3 \sim \text{TiO}_2 \) in the ‘HIMTa’ samples reinforces the differentiation (Fig. III.10.), as already noted by Gallo et al. (2014) and Rosenow and Rehren (2014). The trace oxide pattern further confirms the existence of two sub-groups based on the geochemical characteristics of the glassmaking sands (Fig. III.9.B.), while in the aspect of secondary re-working/ re-melting/ recycling both sub-groups do not differ (Fig. III.9.C.). Finally, the ‘HIMTb’ sub-group features significantly lower phosphorus levels and slightly higher soda than ‘HIMTa’ (Appendix B.2.2.), as well as higher MnO content (Fig. III.7.). However, any definitions and interpretations of particular trends in this internal subdivision at the present stage of research may not be feasible. It should be pointed out that the scatter-graphs confirm the affiliation of the HIT composition (see Section III.2.2.) to the ‘HIMTb’ sub-group in terms of sand geochemistry.

The HIMT glass from the Lower Danube studied here forms a quite consistent archaeological group, with no macroscopic difference between the vessels made of ‘HIMTa’ and ‘HIMTb’ sub-groups. Possibly, fragments made of ‘HIMTb’ glass could be interpreted as evidence of finished vessel imports to the region (see Section V.2.2.), i.e.
Fig. III.11. HIMT and HIT glass samples from the present dataset compared to published data: A. HIMT glass from the 5th c. Western Mediterranean demonstrates similar grouping to the observed ‘HIMTa – HIMTb’ separation from the Lower Danube; B. HIMT glass from North-Western Europe and Britain appears entirely overlapping the ‘HIMTb’ field only.

to assume different routes of supply – a suggestion which at the present stage of research is only tentative. A similar archaeological uniformity across the compositional sub-groups is valid for the HIMT glass from Southern France and Northern Africa (Fig. III.11.A.). This may imply that an internal heterogeneity of the sand deposit, unrecognised or ignored by craftsmen working in an organisationally undivided primary HIMT glass industry was the reason for this variability. Then it had no impact.
on the distribution and further secondary glass working, since supplies of compositionally different sub-groups would have been shipped and re-worked jointly.

However, such a hypothesis contradicts the pattern of the HIMT distribution beyond the Mediterranean (Fig. III.11.B.). Interestingly, the data from Britain and recently published analyses of a particular vessel glass type (the so called ‘helle’ bowls) from North-Western Europe suggest that in the second half/ end of the 4th – first half of the 5th c. AD only glass consistent with the ‘HIMTb’ sub-group has been in use. The same strong correlation and ratio of Fe$_2$O$_3$–TiO$_2$ characteristic for ‘HIMTb’ is seen also in the HIMT glass from Mayen, Germany, dated mostly to the early 5th c. (Grünewald and Hartmann 2014, Fig. 6.5., 6.6.). Moreover, the data in Fig. III.11. shows relatively little blurring between both sub-groups which should be expected if they would have been re-melted as bulk raw material coming simultaneously from a single supply source.

Further analytical data, ideally combined with archaeological research on vessel manufacture and well-defined dating of the finds, would help to understand the meaning of the geochemical sub-division of the HIMT glass – does it represent a purely chronological phenomenon, does it indicate the presence of various contemporaneous but independent production centres, or is related to different supply routes. In contrast to the understanding that HIMT glass has identical characteristics across the Empire (Freestone 2014) the finds from the Lower Danube region corroborate this internal differentiation, and confirm that both sub-groups were in use in the Eastern Balkans during the 5th c. AD, and possibly more actively in its earlier decennia.

III.2.4. Various vessel shapes – colourless/ nearly colourless glass (5th c. Mn-decolourised composition = Série 3.2.)

Fragments of vessels with different shapes that belong to various functional categories, manufactured and decorated using a range of techniques are brought together under this general heading mostly because they share the same visual appearance of glass (colourless, or nearly colourless with light bluish to greenish and yellowish tints) and identical compositional makeup. As mentioned earlier, the initial separation of certain
groups in the archaeological catalogue of the Dichin assemblage (Cholakova 2009b) is not supported by the analytical data, which indicates that these groups are produced of one and the same primary raw glass type. Therefore, combining scientific and archaeological evidence, these various archaeological clusters were merged into a single bigger group, assuming that the secondary workshops which have manufactured them were integrated in the same overarching network of primary glass supplies. Nevertheless, the group is heterogeneous in terms of morpho-typology and also not completely consistent in its chemical composition, probably reflecting certain shifts in production throughout the 5th c. and differences between various ateliers.

The sub-assemblage from Area F of the site provided in total 28 samples of this group (Appendix B.2.6.), which most probably come from 23 or 24 individual vessels. It is believed that this number is representative of the actual proportion of the colourless/ nearly colourless 5th c. glass in Dichin as a whole. These fragments form approximately one third of the entire assemblage and at least half of the glass in circulation during the first period of the site (ca AD 410-490)*. 

A group of wall sherds decorated using cold glass working techniques stands out with their elaborate ornamentation (Fig. III.12., G 18-20). The hemispherical bowl G 20 with part of a cruciform symbol (?) and a single letter preserved from an inscription resembles the ornamental scheme of wheel-engraved bowls Isings 116 discussed earlier (see Section III.2.1.). At the same time, unlike the bowls made of Levantine I glass, this fragment is decorated by shallow abrasion only, suggesting a different and possibly simplified manufacture tradition which possibly just reproduced the original decorative scheme from the Eastern Mediterranean. The association of G 20 bowl and the Levantine I inscribed vessel G 25 is reinforced by the fact that they were found in the same destruction context from the first phase of the first site period of Dichin (ca AD 410-470).

Fragments of the two bowls G 18 and G 19 have identical outlines of their

* This estimation is based on analytical results of Area F glass combined with archaeological study and visual assessment of all the glass fragments found at the site.
Fig. III.12. Dichin – fragments of bowls of various shapes with engraved/ abraded decoration made of 5th c. Mn-decolourised glass composition, ca AD 410-490 (after Cholakova 2009b; Rehren and Cholakova 2014). The detailed picture of G 20 (abraded letter H, bottom right) presents the surface corrosion colour – silvery-pinkish as an effect of the MnO content, but the unaltered glass is colourless with light greenish tint.
preserved decorations: a band of zoomorphic or floral patterns situated between horizontal lines. The techniques of light abrasion and deeper free-hand engraving used in both cases are also very similar. Moreover, the analytical data indicate that G 18 and G 19 have matching chemical compositions, i.e. both fragments were likely made of one and the same batch of glass (see Section VI.1.2.2., Fig. VI.2.). Nevertheless, due to certain differences in their wall sections and details of ornament dimensions, G 18 and G 19 are considered as fragments of two separate vessels. They were found apart, in two different and unrelated contexts, one of them tentatively dated to ca AD 410-470, while the other context is disturbed. Similar decoration on vessels from the Northern Black Sea coast dated to the 4\textsuperscript{th} – 5\textsuperscript{th} c. and interpreted as imports from Syria or Egypt is implemented using paints (Kunina 1997, n431, n432). The floral ornament of G 18 is quite unclear and hardly visible which could possibly be characteristic of a surface alteration left behind by disintegrated painting. Unfortunately, the fragmented state of G 18 and G 19 does not allow more conclusive statements. Nevertheless, these vessels certainly represent luxurious section of the glassware used at Dichin, produced probably in the East Mediterranean during the 5\textsuperscript{th} c., and imported to the Lower Danube region.

The next archaeologically defined cluster of vessels seems to be the dominating one among the 5\textsuperscript{th} c. decolourised fragments from Dichin, but at the same time is quite heterogeneous. It consists of thin-walled bowls/ cups, possibly beakers, and oil lamps, manufactured with a pontil rod. These have carefully shaped fire-rounded rims, plain or decorated using a range of techniques (in total 19 samples). Most of the fragments have significant surface weathering and are too small to allow precise identification of the vessel shapes (e.g. Fig. III.13., G 57, G 58). The only exception is a complete profile reconstruction of a bowl G 45 & G 46 & 47 (Fig. III.12.) found in numerous pieces in the destruction layers of the first 5\textsuperscript{th} c. phase of the settlement (AD 410-470). This vessel belongs to a popular late antique type, with various morphological parallels in the studied region (e.g. Gomolka 1979, Taf. 62, n106; Gomolka-Fuchs 2007, Taf. 51, n1867) and far afield (e.g. Fünfschilling 2009, Fig. 3.12; Ortiz Palomar 2001, Fig. 88/1). Interestingly, similar bowls with abraded decoration are known from Western Europe (e.g. Cruz 2014, Fig. 7.3.14; Price 2000, Fig. 3.9.) but compared to them the
Fig. III.13. Dichin – fragments of vessels of various shapes and decoration made of 5th c. Mn-decolourised glass composition, ca AD 410-490 (after Cholakova 2009b; Rehren and Cholakova 2014).
ornamentation of the Dichin vessel is far too simplified and unskilled. Two more samples – a wall/ base fragment G 22 and a rim fragment G 48 – may be parts of the same bowl even though they do not piece together with the rest of the sherds. However, both samples are compositionally very similar to G 45-47 and could be an output of the same melting event, if not pieces of the same vessel.

Another smaller undecorated fragment of a bowl (G 49) is comparable to the reconstructed vessel but has an inward turned rim section resembling one of the HIT sherds (cf. Fig. III.6., G 3). A similar basic manufacturing technique of fire-rounded and thickened rim edge is used for a range of vessels made of the same decolourised glass and decorated with thin trails of blue transparent glass (Fig. III.13., G 54-59). These fragments come from various bowls, deeper cups or beakers, and possibly oil lamps as well. However, this formal diversity is linked mostly to the functions and usage of the vessel and not to the manufacturing characteristics. The fragments share a unifying base glass composition, identical fire-rounded rim shaping, and quite distinct blue trail ornaments. The spiral trails are marvered flush with the vessel wall surface, or left semi-marvered indicating a skilful glass-working tradition for hot manipulation of two different glass-melts, possibly with different working properties (cf. Conte et al. 2014, samples 39 and 39(a) – a rim of the same 5th decolourised glass decorated with HIT Co-coloured trails)\(^*\). The fashion of such decoration is likely influenced by East Mediterranean tradition (e.g. Jennings 1997/1998, Fig. 24) and has its further developments in the Western regions of the Empire (e.g. Foy 1995, Pl. 13-14). At the same time, numerous examples of blue trail decorated vessels from the Balkans (e.g. Shepherd 1999, 327; see Section VI.2.3.1.) indicate that at least a certain part of them was regionally manufactured.

A few more fragments belong to the same archaeologically outlined cluster: a slightly concave oval base with pontil mark (Fig. III.13., G 65), three sherds of similar oval bases with traces of abrasion or plain (G 21, G 23, G 66), and pointed bases of oil lamp (Fig. III.13., G 80, G 81). This distinct type of oil lamps designed as suspended

\(^*\) Hypothetically, it seems that the blue glass of the trails was stiffer than the glass of the vessels and the threads are worked into the vessel wall during the final blowing/shaping of the rim (M. Taylor pers. comm.; cf. Foy 1995, 204). Analysing separately the glass composition of the blue decoration was beyond the remit of the present work.
lighting devices could be part of the blue trail decorated vessels, even though plain pointed lamps are also known (cf. Cholakova 2009b, 277-278; Uenze 1992, Taf. 50, 12-18).

The last find only tentatively to be assigned to this group is a thin and straight wall fragment with a single abraded line (G 24) which could be part of a beaker or a jug but no definite identification of the vessel shape is possible.

Twelve fragments, out of these 19 briefly described above, were found in well-dated contexts in Area F, all of them belonging to both phases of the first period of the site (ca AD 410-490). The observations on the entire site assemblage confirm a continuous presence of blue trail decorated glassware throughout the whole 5th c., and possibly its more active usage towards the end of the first site period.

A smaller cluster of four fragments decorated with self-coloured trails also belongs to the compositional group of 5th c. decolourised glass. Two of them are jug/flask sherds (Fig. III.13., G 82, G 83); dated respectively to ca AD 410-470 and ca AD 470-490) and the other fragments may be reconstructed as drinking cups/bowls (Fig. III.13., G 85, G 86); the first dated to ca AD 410-470). The finds do not represent a consistent archaeological entity but they differ from the rest of the vessels by their technique of decoration – thin spiral self-coloured threads standing in relief. Formally they resemble the blue trail fragments but the self-coloured ornamentation covers more than just the rim area of the vessels, and it is incompatible with marvering technique. Therefore, these vessels may represent a different manufacturing tradition, probably remnant of an earlier technological style, more characteristic of the Roman/late Roman 4th c. glass tableware (e.g. jugs Isings 120).

Finally, two fragments G 43 and G 44 (Fig. III.13.), most probably belonging to one and the same hemispherical bowl, represent a quite simplified technology of outsplayed and cracked-off rim, only slightly smoothened. They are made without pontil and with no hot working finishing. Both pieces were found in destruction layers of the first 5th c. phase of the site (ca AD 410-470). This bowl is rather unusual within the present group of 5th c. decolourised glass, generally comprising of vessels produced with pontil. At the same time, other similar decoloured fragments of cups/bowls with
cracked-off rims excavated at other areas of Dichin (Cholakova 2009b, Table IV) indicate that the find from Area F is not exceptional. These vessels may represent some smaller scale unsophisticated production, possibly associated with the contemporaneous HIMT vessel manufacturing (cf. G 12; see Section III.2.3.).

This summarised overview of the artefact characteristics of the fragments included in the present group indicates a significant diversity of shapes and manufacturing techniques. Even if made of raw glass of the same chemical composition, these vessels are likely produced in different secondary workshops. Certain exceptional pieces with sophisticated decoration (e.g. G 18, G 19) were made in ateliers of higher artistic level, most probably located outside the Lower Danube region. Other, more numerous and widespread groups such as the blue trail decorated vessels could be production of regional level, while plain fragments manufactured with rather basic techniques (e.g. G 43 & G 44) might be linked to smaller scale local workshops. Nevertheless, the compositional uniformity and the common 5\textsuperscript{th} c. date strongly suggest that these finds should be considered as a single group in the present classification. Taking into account their abundance in Dichin and the fact that they present at least half of all the glass used during the first site period (ca AD 410-490), it is plausible to recognise the majority of them as production of the secondary workshops situated within the studied region. Not much is known for certain about these workshops’ repertoire. However, it presumably covered a range of functional categories (e.g. tableware, oil lamps, etc.), and included an assortment of different levels of quality, as well as a certain (and also evolving over the time) variability of manufacturing techniques. Accordingly, the present group is an expected reflection of this diversity. Nevertheless, the preferred approach here is to explore this group as a unity, since from the viewpoint of distribution networks these secondary workshops had more or less identical positions – they received the same raw glass supplies and served the same consumption needs within the Lower Danube region.

The present group is identical with a chemical glass composition defined for the first time among the late antique glass finds from Southern France, and labelled as Série 3.2. (Foy et al.2003, Tab. 14). This composition is characterised by relatively low concentrations of mineral impurities, i.e. made from relatively clean glassmaking sand,
and by intentionally added manganese acting as glass decolouriser (approximately within the range of 0.5–1.0 wt%. MnO). The low levels of alumina and to a certain extent lime (mean values of Al$_2$O$_3$ ca 1.9 wt% and of CaO ca 6.54 wt% for samples from Dichin; averages from the entire studied dataset are presented in Table III.4.) are of particular importance since they separate this group from other known Mn-containing compositions (e.g. blue-green glasses in Foster and Jackson 2009; High-Mn and Low-Mn in Jackson and Paynter 2015, 6-8). At the same time, such low alumina and lime values strongly resemble the composition of antimony decolourised glass popular during the earlier Roman period (e.g. Groupe 4 in Foy et al. 2004) but also used in Late Antiquity as well (e.g. Type 1 in Meek 2013, cf. SER 28, Section V.2.3.). Relatively high concentrations of soda in the 5th c. samples (ca 19 wt% Na$_2$O) also support this comparison since Sb-decolourised glass often features high soda levels (e.g. Thirion-Merle et al. 2002-2003). However, at the present stage of research, it may not be plausible to draw direct conclusions about a common provenance of both glass groups on the basis of these compositional similarities. A significant chronological gap between them and a clear trend for correlated increase of Al$_2$O$_3$ and CaO concentrations in the 5th c. Mn-decolourised glass (Fig. III.14.) should also be taken into account since they underline the difference between both groups. Finally, the isotopic analyses may provide certain hints regarding the provenance of the 5th c. Mn-decolourised glass but so far the available data is limited and inconclusive (Maltoni 2015; Maltoni et al. 2015).

The Mn-decolourised glass composition found in 5th c. vessel fragments in Dichin is attested in other regions of the Empire, too, even though the group does not seem to be widely distributed or recognised. Five vessel fragments from a 4th c.
Fig. III.14. 5th c. Mn-decolourised glass samples from the present dataset compared to published data from the Mediterranean and Britain. An internal (chronological?) trend for correlated increase of alumina and lime is evident throughout the group. Note two samples-outliers (SER 31 and SER 55) which also differ in certain minor oxide values.

context in Britain are probably among the earliest examples of this makeup (Foster and Jackson 2010, Group 2a), and they also demonstrate the lowest alumina and lime values of this composition (Fig. III.14.). A small set of window pane samples from the region of Singidunum (present-day Belgrade in Serbia) belongs to the same compositional group, possibly dated to the (late?) 4th c. AD (Marić-Stojanović et al. 2015, Group K1). Three sites from Northern Italy – Aquileia, Padova, and Classe, provide evidence that the Mn-decolourised glass was in circulation in this region during the 5th and the 6th c., used as vessels and mosaic tesserae (Gallo et al. 2014, AQ/3; Silvestri et al. 2011, MSG1c; Maltoni et al. 2015, CL3). The dated samples from Southern France (Marseilles), published by Foy et al. (2003) with the well-known label Série 3.2., belong to the very end of the 5th – beginning of the 6th c. They are broadly

* The analysed fragments come from unstratified and not dated disturbed contexts from Stojnik castrum. The site is generally dated to the 2nd – 4th c. AD, with no evidence of 5th c. occupation but a very active habitation phase during approximately the third quarter of the 4th c. (S. Stamenković, M. Glumac, M. Vasić pers. comm.). Accordingly, these samples of MnO-decolourised composition, with average values of ca 2.0 wt% Al₂O₃ and 6.3 wt% CaO likely represent a pre-5th c. instance of this makeup.
Fig. III.15. The 5th c. Mn-decolourised glass samples from the present dataset: intermediate sub-group with higher SrO, P₂O₅ likely indicates complex geochemical variations of the sand deposits (A., B.) but not a straightforward shift to the later 6th c. composition (C.). Note different directions of the SrO-CaO correlations in the main and the intermediate group (B.).
contemporaneous to the latest Mn-decolourised finds from Dichin, where an approximate *terminus ante quem* of ca AD 490 for the 5th c. occupation is accepted. Interestingly, the data from Dichin and Southern France presents the highest Al₂O₃ and CaO concentrations (Fig. III.14.), reinforcing the possibility of a gradual compositional change of the sand deposits (deterioration of quality?) over time.

Several more instances of late antique Mn-decolourised glass with low levels of alumina and lime may be tentatively assigned to Série 3.2. primary group (e.g. from Butrint – Conte et al. 2014, sample BT17; from Bubastis – Rosenow and Rehren 2014, sample wH01). Unworked glass chunks of similar chemical makeup from Iustiniana Prima are of particular interest since they would possibly confirm the distribution of this composition well into the 6th c. (earliest probable date for Iustinana Prima glass is ca AD 535 – Drauschke and Greiff 2010, e.g. sample 273). However, the complexities of primary glass group recognition and the range of different terminologies used in the present-day analytical research may hinder the correct identification of Série 3.2., especially when represented by a limited number of samples. Another reason for this often ambiguous interpretation of such Mn-decolourised late antique glasses comes from the internal variability of the Série 3.2.

The following paragraphs provide a summarised overview of this internal heterogeneity and its implications for the interpretation of the studied glass from the Lower Danube region. The discussion takes into account all the Mn-decolourised samples from Dichin, Serdica, and Odartsi, mostly coming from contexts dated to the 5th c. (hence the group is labelled here as 5th c. Mn-decolourised composition) but also probably to the end of the 4th c. and the very early 6th c. AD (see Section V.2.4.).

As mentioned earlier, the 5th c. Mn-decolourised composition features generally low levels of accessory minerals in the glassmaking sands, evident from low alumina and lime concentrations (Fig. III.14.) but also from the minor oxide values and the trace oxide pattern (Table III.4., Appendix B.2.6.). This compositional trait of Série 3.2. gives ground to interpret it as part of the Syro-Palestinian primary glass production according to Foy et al. (2003). However, the opportunity to study a bigger and
relatively well-dated set of samples in the present project allows for identification of an internal trend for gradual increase of almost all sand-deriving minor and trace oxides, as noted earlier for the Dichin glass (Rehren and Cholakova 2014). A separation of a sub-group within the 5th c. Mn-decolourised composition, consisting of ten samples only, is most apparent in CaO, P$_2$O$_5$, and SrO levels (Fig. III.15.A., B.). This sub-group is labelled as ‘intermediate’ because of its position between the main Mn-decolourised cluster and the chronologically later 6th c. composition (e.g. Fig. III.15.A.; the main discussion on the 6th c. composition is given in Section IV.2.2.). Nevertheless, it seems that a complex geochemical variability of the glassmaking sands used for the 5th c. Mn-decolourised primary production defines this sub-group, rather than just a linear shift towards the 6th c. composition.

The increase of strontium oxide is one of the most striking peculiarities of the intermediate sub-group since it resembles the elevated SrO values in the 6th c. composition (Cholakova et al. 2015). The scatter-graph of strontium oxide and lime demonstrates nearly full overlap of both clusters (Fig. III.15.B.), ruling out the interpretation of the intermediate sub-group as resulting from mixed recycling of both main compositions. However, the excess of SrO in the 6th c. glass is likely related to the additive used as part of the glassmaking recipe (see Section IV.2.2.; Fig. IV.11.A.), while in these intermediate samples it is clearly correlated with P$_2$O$_5$ (Fig. III.15.A.). Therefore, a different source of strontium may be supposed. Fuel ash/ vapour contamination cannot be definitely ruled out here but an alternative explanation is also possible – mineral sand impurity would also affect the SrO–CaO ratio (Fig. III.15.B.) if containing variable amounts of SrO and P$_2$O$_5$ (e.g. strontium-apatite, Chakhmouradian et al. 2002) and being unintentionally introduced to the glass melt.

The samples belonging to the intermediate sub-group of the 5th c. Mn-decolourised composition are situated at the extreme end of the ranges of iron oxide, potash, magnesia, and titania, again resembling the makeup of the later glass group. Nevertheless, such an increase of the absolute values does not necessarily indicate a

---

* The overall number of the analysed samples is 44, including two outliers (see Appendix B.2.6.) which is almost twice more than the biggest dataset of 5th c. Mn-decolourised composition published so far (Maltoni et al. 2015, 25 samples from Classe).
Fig. III.16. The 5th c. Mn-decolourised glass samples from the present dataset: the intermediate sub-group fits the direction of correlation of the main group, even if displaying higher absolute values, while the 6th c. composition samples cluster very close but still separately (A.); the partial overlap between the intermediate sub-group and the 6th c. glass points to a certain proximity of both main glass groups (B.). Note the position of the outliers of the 5th c. Mn-decolourised glass (A.) which may indicate mixing with HIMT composition.
straight transition to the 6th c. composition since certain oxide correlations differ in their directions when the intermediate sub-group and the 6th c. composition are juxtaposed (Fig. III.15.C.; Fig. III.16.A.). These patterns probably signify distinct geochemical characteristics of two similar but still separate sand deposits (although quite possibly related/neighbouring), rather than a gradual deterioration of the same raw material source, continuously exploited from the very early 5th c. (or late 4th c.) to the early 7th c. Therefore, taking into account these differences, the intermediate sub-group is interpreted as an intrinsic part of the 5th c. Mn-decolourised composition but not as a transitional stage to the 6th c. composition, even though a certain overlap of their geochemical features exists (Fig. III.16.B.).

In the aspect of glassmaking recipe, i.e. the parameters of glass composition deliberately controlled by the ancient producers, the intermediate sub-group has even stronger links to the 5th c. Mn-decolourised glass. The average concentrations of MnO in the 5th c. composition are about 0.8 wt% (Table III.4.), and the intermediate sub-group is more or less consistent with the main group (see Section IV.2.2., Fig. IV.8.A.). Another technological characteristic (as opposed to geochemical ones) of the intermediate sub-group is evidence of cullet recycling. The increased concentrations of P$_2$O$_5$, MgO, and K$_2$O in these samples may be seen as a result of fuel ash and vapour contamination due to repeated re-melting. However, the overall levels of recycling indicators in the 5th c. Mn-decolourised composition are quite low (see Section VI.2.2. – Fig. VI.4.). If some difference between the main group and the intermediate group is seen here*, it is still negligible compared to the scale of recycling in the 6th c. glass (see Section IV.2.2.). The main discriminator is antimony oxide which is virtually missing in the 5th c. Mn-decolourised composition, and re-appears again in trace concentrations in the 6th c. glass (see Section VI.3.2.2.). At the same time, the intermediate position of the sub-group is again confirmed by slightly elevated values of Sb$_2$O$_3$ and CuO in individual samples (SER 42, ODR 1, ODR 36; Fig. IV.12.B.; Fig. VI.4.).

Logically, when the intermediate sub-group is outlined as part of the 5th c. Mn-decolourised composition, a question about its chronological position arises, i.e.

---

* For example, 21 ppm CuO as mean value for the main 5th c. group and 39 ppm CuO for the intermediate sub-group (see Appendix B.2.6.).
whether these intermediate samples represent a later development of the main group, which indicates certain similarities to the 6th c. vessels. Unfortunately only two samples, out of ten in total in the intermediate sub-group, were found in reliably dated contexts, both belonging to the second phase of the first site period of Dichin (ca AD 470-490). This date is suggestive of a change over time, even though not entirely conclusive.

Therefore, having refined the compositional grouping within the 5th c. Mn-decolourised glass, a return back to the aspect of vessel morpho-typology and manufacturing techniques could possibly clarify the chronology of the intermediate sub-group. As mentioned above, the sub-group consists of ten samples in total, one of them – a chunk of unworked glass (SER 3). The nine vessel fragments belong to various functional groups and shapes (see Appendix A.2.). Three rim sherds are blue trail decorated, another one is plain, with typical fire-rounded thickened edge. Furthermore, an undiagnostic wall fragment has abraded decoration, and a pointed base sherd of an oil lamp is also present in the sub-group. Such a broad range of artefact characteristics fits convincingly the overall archaeological outline of the 5th c. Mn-decolourised group from the first site period of Dichin. However, three stemmed goblets Isings 111 found in Serdica and Odartsi (SER 41, SER 42, ODR 1) also belong to the same intermediate group even though this vessel shape is almost always manufactured using 6th c. composition glass in the present dataset (see Section IV.2.2).

The summarised overview of the vessel shapes and manufacturing techniques in Appendix A.2. illustrates the distribution of various archaeologically defined groups across the glass compositions which dominated the Lower Danube region during the 5th and 6th c. The position of the 5th c. intermediate sub-group suggests that its circulation most probably coincided with a transformation of vessel manufacturing practices and repertoire rooted in the 5th c. traditions and with a shift towards the production range of the 6th c. secondary glass working in the region*. Accordingly, it is quite likely that the presence of this sub-group in the studied region should be tentatively dated to the late 5th – very early 6th c. It possibly marked the final decennia

---

* The correlation of the changes in vessel shapes and manufacturing techniques and the changes in chemical glass compositions throughout the 5th – 6th c. is discussed in detail in Section IV.2.2.
of economic activity of the primary glassmaking centre(s?) which was the source of the 5\textsuperscript{th} c. Mn-decolourised composition.

III.2.5. Stemmed goblets – various glass tints (6\textsuperscript{th} c. composition = Série 2.1.)

The last main group in the Dichin assemblage has certain links to the 5\textsuperscript{th} c. Mn-decolourised glass, as discussed above, but on the other hand, to a certain extent it represents an opposite of the earlier glass. The vessels made of 5\textsuperscript{th} c. Mn-decolourised composition from Dichin demonstrate a diversity of shapes and manufacturing techniques but they all look colourless or nearly colourless, indicating attention to the visual appearance of the melt and most probably an ability of the craftsmen to control and maintain it. Unlike this production tradition, almost all the fragments in the present group within the Dichin assemblage belong to a single vessel type – stemmed goblet Isings 111, shaped in a quite uniform and standardised process, but requiring good level of technical skills and certainly not simple (Fig. III.17.A.). Regardless of this morphological uniformity, the sherds show a variety of glass tints: from nearly colourless or yellowish, to blue-green and darker green colour. Apparently, the visual aspect of these vessels was not a matter of importance, or the control over the glass colour has been beyond the craftsmen’ skills and knowledge. However, most of the analysed fragments from Dichin Area F have relatively steady yellowish colour (Fig. III.17.) but stemmed goblets with darker green tints are found in the site assemblage, too (Rehren and Cholakova 2014, Fig. 11.9.13.).

The present group consists of 19 samples in total (Fig. III.17., Appendix B.2.7). Eleven of them come from stems, bases, or middle parts of Isings 111, while four rim fragments could probably be reconstructed as upper parts of the same type, even though they could also belong to other vessel shapes (e.g. oil lamps with pointed bases – Cholakova 2009b, Tabl. XI.1). Furthermore, three samples are flat window pane pieces (G 38, G 70, and G 87). Only a single fragment (G 63) undoubtedly belongs to a vessel shape different from Isings 111. This small piece of a slightly pushed-in base is too narrow to be reconstructed as tableware. It most probably comes from an oil lamp with narrow cylindrical lower part (Fig. III.17.B.), a type which is well-known from the 6\textsuperscript{th} c. Lower Danube region (Olczak 1995, Fig. D/A2; Băjenaru and Băltăc 2000-2001,
Fig. III.17. Dichin – fragments of stemmed goblets Isings 111 made of 6th c. glass composition, ca AD 540-580 (after Cholakova 2009b). The rim fragments G 50-52 could come from oil lamps but G 63 is the only surely identified lamp. **A.** Reconstruction of the process of stemmed goblet manufacture (after Stern 2012); **B.** Oil lamp with narrow cylindrical lower part from Novae – this vessel type is the suggested reconstruction of the base fragment G 63 (after Olzcak 1995).
All the vessels in the present group are manufactured with a pontil rod and their preserved rim fragments have fire-rounded edges, somewhat resembling the 5th c. thickened rim profiles. One of the sherds has a slightly ribbed surface made with optic blowing (G 52) but in general the group has no decoration. The goblets found at Dichin are blown from a single gather of glass, with stems shaped from its lower part (Fig. III.17.A.; as opposed to stems produced separately from a second gather of glass). Interestingly, most of the unbroken Isings 111 stems from the site (and all of the unbroken stems from Area F) are shaped with a ball knop or similar smaller projection. This peculiarity of the goblets from Dichin separates them from the majority of the finds from Odartsi (a detailed discussion on Isings 111 in given in Section IV.2.2.). Isings 111 with ball knops were also found in the immediate vicinity of Dichin (e.g. Shepherd 1999, n271-273), and the broader Lower Danube region (e.g. Băjenaru and Bâltâc 2000-2001, Pl. VI.5, 6), but this should not be seen as a regional specific. Such a detail of manufacture rather marks a wider production tradition, also found in Greece (Stern 2012, n346-352), Asia Minor (e.g. Gill 2002, Fig. I.5), and farther afield (e.g. Gorin-Rosen and Winter 2010, Fig. 3). Stemmed goblets are probably the most indicative glass type in the early Byzantine assemblages from the Mediterranean and the Balkans. However, the analysed goblets are certainly manufactured within the Lower Danube region, as inferred on the basis of their overall modest quality, the fact that this type forms approximately one-third of the entire vessel glass assemblage from the site (i.e., its high frequency of distribution), and also taking into account available evidence from secondary workshops in Moesia Inferior (e.g. Minčev 1992, 75, Abb. 6; Olczak 1998, 44-48, Fig. 12).

The chronology of the samples in the present group needs a brief comment. Stemmed goblets were the only vessel glass fragments found in secure 6th c. contexts of Area F (ca AD 540-580), and all of the analysed examples belong to one and the same chemical group, accordingly labelled as ‘6th c. composition’. However, Isings 111 sherds (including some that were analysed and match the 6th c. composition) were
occasionally recorded in 5th c. contexts of Area F, too*. It cannot be definitely stated
whether the vessel type, respectively the chemical composition, had such a long-
standing presence in Dichin, without interfering with any of the other of 5th c. groups
at the site. A likely explanation of this unusual (and not quite logical) pattern is that
individual pieces of glass which circulated during the 6th c. period of the site may
accidentally have been deposited in earlier or disturbed contexts. Therefore, taking
into account the data from Odartsi and Serdica, the present group is considered more
generally as a phenomenon of the 6th c. This is also in good accordance with the
interpretation of the overall site development of Dichin (see Section IV.1.1.).
Nevertheless, the question about the moment when the 6th c. composition emerged in
the Lower Danube region (respectively, the question of its possible chronological
overlap with the earlier 5th c. Mn-decolourised glass) needs further research and finds
with better chronology and dating.

The chemical makeup of the present group from Dichin is consistent with Série
2.1. of Foy and co-authors (2003), and it is discussed elsewhere as part of the general
overview of the 6th c. glass from the entire studied dataset (see Section IV.2.2. – ‘6th c.
composition’). However, it needs to be pointed out that only five samples (G 50, G 69-
71, G 87), out of 19 in total identified as 6th c. composition at Dichin, belong to an iron-
rich subgroup outlined within the main type. This proportion (a ratio of approximately
1:4) has a particular significance, knowing that this site assemblage is dated up to ca
AD 580 and does not cover the very end of the 6th c. As mentioned in regard to the 5th
c. Mn-decolourised glass, a juxtaposition of the main chemical compositions/ sub-
groups of the 5th – 6th centuries with the archaeologically defined and datable
categories of vessels (Appendix A.2.) implies a certain chronological sequence of
different glass makeup varieties. Hypothetically, the 6th c. glass from Dichin marks the
initial moment of emergence of this iron-rich subgroup, approximately in the third
quarter of the 6th c., while towards the end of the 6th c. a nearly equal distribution of
the main group and the subgroup is seen (e.g. Odartsi, see Section IV.2.2.).

* According to the field documentation, four samples of the present group were found in contexts dated
to ca AD 410-470 (G 50, G 71, G 79, G 87), and three come from contexts dated to ca AD 470-490 (G 38,
G51, G 76). The remaining 12 samples belong to secure 6th c. contexts, or come from disturbed layers.
III.2.6. Overview of the Dichin assemblage in terms of chemical glass compositions

The previous sections provided a detailed discussion of the glass finds in the Dichin assemblage in terms of artefact characteristics (vessel shapes and manufacturing techniques), evidence of dating and origin of the finished vessels, and chemical makeup. The presence of five main groups outlined in the current classification (corresponding to Levantine I, HIMT, HIT, 5th c. Mn-decolourised, and 6th c. composition) demonstrates a diversity of the primary glass compositions attested at the site in the 5th – 6th c. At the same time, this diversity has its own pattern which reflects the dynamics of economic and site development of Dichin. Several important points regarding this variety of primary glass groups are summarised below.

- A clear contrast exists between the glass dated to the first main period of the site (ca AD 410-490) and the finds from the second main period (ca AD 540-580), indirectly supporting the conclusion about a chronological hiatus between the 5th c. occupation and the 6th c. settlement.

- The glass groups dated only to the 5th c. period of the site (i.e. Levantine I, HIT, HIMT, and 5th c. Mn-decolourised composition) are not attested in any of the contexts in Area F securely dated to the 6th c. The only group which can be definitely assigned to these contexts is the 6th c. composition, even though its presence during the first site period cannot be completely ruled out.

- In terms of an overall quantification of the entire assemblage*, approximately one-third of all the glass is formed of stemmed goblets Isings 111, all of them made of 6th c. composition according to the analysed samples. The glass made of 5th c. Mn-decolourised composition represents another one-third, while Levantine I, HIT, and HIMT together constitute the last one-third of the total assemblage (with a slight prevalence of HIMT glass over the other two groups).

- Nevertheless, no reduction of glass vessel usage should be seen in the 6th c. period of the site because the 6th c. occupation lasts only about half as long as the 5th c. occupation.

---

* As mentioned earlier in the discussion, these approximate estimations are based on analytical results of Area F glass combined with archaeological study and visual assessment of all the glass fragments found at the site.
• Vessels imported as finished objects from far afield belong to the Levantine I, HIT, and possibly individual examples of the 5th c. Mn-decolourised composition, often acquired as one-off higher quality deliveries to the site. Regionally and/or locally produced vessels are made of HIMT, the 5th c. Mn-decolourised, and the 6th c. composition. There is no evidence of imported vessels from the 6th c. period of the site, according to the finds from Area F.

• The 5th c. site period features two separate phases, and certain differences exist between the glass groups used during these phases. The HIMT fragments are documented in some of the earliest contexts (ca AD 410). This group seems more actively used during the first phase (ca AD 410-470), even though it is found during the second phase (ca AD 470-490) as well. The Levantine I glass is present during the first phase only, while the HIT composition belongs entirely to the second phase. The 5th c. Mn-decolourised glass is found in contexts dated to both phases, with a likely compositional shift (i.e. emergence of the intermediate sub-group) toward the end of the 5th c.

Summarising these patterns opens direction for further interpretations of the distribution networks in the wider historical and socio-economic context of the Lower Danube region (see Chapters VI and VII). The Dichin assemblage is the mainstay for reconstructing these networks in the present project since it is an integral archaeological unity. This objective and comprehensive insight into the glass used during the 5th – 6th c. is largely unaffected by certain technical factors, such as insufficiently documented stratigraphy, selective/incomplete assemblage preservation, severely restricted sampling, etc.
Finally, four more samples from Dichin should be mentioned separately (Fig. III.18., Appendices B.2.4.; B.2.5.; B.2.8.), because they stand as compositional (and also to a certain extent archaeological) outliers, compared to the main five glass groups.

Two base fragments (G 84, G 67) found in the same context from the first 5th c. phase of the site (ca. AD 410-470) differ from the majority of the glass in their colour and manufacturing characteristics. G 67 has a tubular base ring formed from the vessel body (a cup?), a production technique which is closer to earlier Roman and late Roman tradition and has no analogies among the Dichin assemblage, except a single fragment (Cholakova 2009b, Tabl.IX.1.). The other fragment (G 84) is too small to be precisely identified but could be a (mould-shaped?) flat bottom, similar to some late Roman finds (e.g. Sterrett-Krause 2009, Fig. 6; Schibille et al. 2016 about the composition of these finds). The ring base is nearly colourless, with pale greenish tint, while the other find is made of clear colourless glass. Chemically both samples show significant levels of S\(_2\)O\(_3\) (nearly 0.4 wt% in G 84 and 0.6% in G 67). The presence of antimony brings to the batch also additional As\(_2\)O\(_3\), probably as a contamination in the minerals used, and both G 84 and G 67 have elevated As\(_2\)O\(_3\) values (33 ppm and 55 ppm respectively). The first fragment belongs to the typical antimony decolourised glass composition, with low mineral impurities and MnO at trace levels (130 ppm), supposed as natural in the glassmaking sands (see Section V.2.3.). However, its elevated SrO content (800 ppm) remains puzzling.

Despite its high antimony content, sample G 67 indicates mixed recycling of Sb-and Mn-decolourised compositions, with approximately 0.2 wt% MnO. Its relatively low concentrations of alumina, lime, iron oxide, and other minor oxides are consistent
with the chemical makeup of mixed glasses used in the regional secondary glass working in the late 3rd – 4th c. (see Section V.2.6.).

It may be plausible to explain the presence of G 84 and G 67 at the site as traces of certain temporary/short-term/space-limited habitation on the hill during the 3rd – 4th c./the late 4th c. The original layers from that time could be entirely destroyed (i.e. both fragments were re-deposited) during the 5th c. construction, or could be situated outside the excavated areas of the site. An alternative interpretation of the fragments as heirlooms intentionally kept by the inhabitants of the 5th c. settlement (accordingly, deposited in later contexts) cannot be ruled out. However, given chronological distance and the fragility of glass vessels, this is actually highly improbable.

The remaining two outliers are a base fragment of a bowl (G 64) and a small rim fragment (G 62). They come from two unrelated contexts, one of them dated to ca AD 410-470. However, the closely overlapping chemical compositions of both fragments indicate that they could be part of one and the same vessel, or output of the same melting episode. Their colour is bluish, visually resembling the bowls Isings 116 made of Levantine I glass (Fig. III.4.). At the same time, the vessel manufacturing characteristics are completely different – slightly pushed-in base with traces of very carefully pontil-removal, fire-rounded rim edge with thin self-coloured trail decoration. Any reconstruction of the vessel shape would be hypothetical due to the small size of the preserved fragments but it could be a small cylindrical cup with straight vertical rim, not matching any of the main glass groups in Dichin. Compositionally these samples are also outliers, with their intermediate values of iron oxide (ca 1.1 wt%), titania (ca 0.3 wt%), ZrO$_2$ (ca 195 ppm). The content of ca 0.7 wt% MnO balances the elevated iron oxide, giving the light bluish glass colour. Tentatively, it could be expected that such intermediate values of heavy mineral impurities in the glassmaking sand may come from mixed recycling of equal amounts of HIMT composition and glass with a ‘cleaner’ makeup. However, the trace oxide ratios situate G 64 and G 62 much closer to the field of Egyptian HIMT group (Fig. III.9.B.), suggesting that they could represent some of the varieties of primary raw glass groups produced in Egypt, possibly close to HIMTb sub-group (e.g HIMT 1 of Foster and Jackson 2009). Nevertheless, the
completely different visual appearance and vessel manufacturing techniques separate these samples from the HIMT group from Dichin and the Lower Danube region known so far. Possibly, it is a rare case of a single vessel import from far afield which adds to the range of one-off supplies to the site, like the HIT vessels.

Five main groups are identified in Dichin site assemblage on the basis of integrated archaeological and archaeometric evidence. Bowls with wheel-engraved decoration made of Levantine I glass and vessels with fire-rounded rims made of HIT glass likely represent import of finished objects to the Lower Danube region, in some cases as one-off acquisition to the site of Dichin. The majority of the vessels used during the first occupation period of the settlement are made of 5th c. Mn-decolourised composition, and they probably represent the diverse production of the secondary workshops within the regions. Vessels made of HIMT composition are also dated to the first period of Dichin but they have different craft style characteristics. The 6th c. period of Dichin marks a significant shift in glass usage, distinguished by a single chemical glass composition and almost total prevalence of a single vessel shape – the stemmed goblets produced using pontil technique.
Similarly to the previous Chapter III about the Dichin glass finds, the current Chapter IV presents the next site assemblage in this study excavated at the Odartsi site. In order to maintain a consistent structure of the thesis, the discussion of the Odartsi materials follows the model of the text about Dichin. A summarised overview of the site characteristics and chronology is outlined in the beginning of Chapter IV; a brief description of the assemblage and the approaches to its sampling are also included. Furthermore, the two main groups identified in this site collection are presented in detail, both in terms of vessel features and chemical composition. Several fragments are brought together as *varia* since they cannot be assigned to either of the main groups.
IV.1. Introduction

The archaeological fieldwork at the Odartsi site revealed a late antique fortified settlement dated between the 4th and very beginning of the 7th c. AD. Although comparable to Dichin in various aspects, it should be noted that the occupation of Odartsi is longer, spanning until ca AD 610-615. This extended chronology and the abundant finds from the 6th c. contexts provide an opportunity to broaden the interpretations based on Dichin glass, and to study in detail the vessels from the final decennia of Late Antiquity in the Eastern Balkans. A summarised introduction to the site followed by an overview of the assemblage from Odartsi is given in the first part of the Chapter IV.

IV.1.1. The site

The fortified hill-top site is situated approximately 1 km to the South of the modern village of Odartsi, municipality of Dobrich in North-Eastern Bulgaria. The fortress is positioned on a hill with steep slopes – a small promontory projecting from the Southern edge of the Dobrudzha plateau (Fig. IV.1.). This locality was preferable for habitation because of its natural terrain, well-suited for military defence. During the Roman period and Late Antiquity it remained a remote rural area away from the main roads but still only ca 25 km from Odessus – the main ancient city and trade port in this part of the Black Sea coastline, and from AD 536 the seat of Justinian’s quaestor exercitus (see Section I.2.1.).

The Odartsi site was extensively excavated from 1969 to 1992 by a joint Bulgarian-Polish team. The hill-top area was formally divided in ‘Western’ and ‘Eastern’ parts, with the Western Sector being excavated by the team from Poznan* in 1969 – 1979 (Kurnatowska and Mamzer 2007). Initially, the Bulgarian team of the Institute of Archaeology and Ethnology – Polish Academy of Sciences, Poznan branch.

* Institute of Archaeology and Ethnology – Polish Academy of Sciences, Poznan branch.
Archaeology – Bulgarian Academy of Sciences worked in the Eastern Sector, but later, in 1980 – 1990 they also excavated in the Western part of the site (Dončeva-Petkova and Torbatov 2001). The fieldwork uncovered remains of multiple occupations on the hill and in its surroundings, with elaborate stratigraphy and chronology (Fig. IV.2.). According to the most recent studies, the earliest remains are dated to the Chalcolithic
Fig. IV.2. Odartsi – plan of the site and its surroundings; the late antique buildings are marked as open outlines, the medieval houses and structures as black outlines (after Dončeva-Petkova et al. 1999; Torbatov 2002a).
period, followed by traces of habitation from the Late Bronze Age and the Early Iron Age. A fortified Thracian settlement existed on the same place in the second half of the first millennium BC (Torbatov 2002a). However, the remains dated to all these early phases of the site were severely disturbed during the later large-scale building works in Late Antiquity and the Early Middle Ages.

The late antique occupation on the hill began after a hiatus of more than three centuries. According to an integrated analysis of the architectural planning and the coin circulation, the initial construction of the defensive walls possibly took place during the first half of the 4th c. AD, and more precisely in the 330s, within the framework of the systematic building programmes of Constantine I in the province of

---

**Fig. IV.3.** Plan of the late Roman and early Byzantine fortification of Odartsi: A. Outline of the defences built during the first half of the 4th c. AD, followed by later phases of repairs and new constructions; towers are indicated numerically (after Torbatov 2002a); B. Detail of the towers 3 – 5 in the North-Eastern part of the fortification with adjacent buildings and streets; the street pavement at tower 3 and the separations of internal spaces in the buildings belong to the 6th c. period of the site (after Dinchev 2006).

* The following summary of the site chronology and its interpretation is based on the works published by S. Torbatov (2002a, 2002b), on unpublished research of the same author, and partly on Dončeva-Petkova et al. (1999).
Scythia Minor. The carefully built fortress with a polygonal plan, surrounding an area of ca 1.1 ha and reinforced with six towers, was erected after a certain levelling of the terrain. The defences were well-adapted to the outline of the hill, with their most heavily secured front at the Northern side (Fig. IV.3.A.). Additionally, an external ditch was constructed at a distance of 25-30 m from the Northern walls. The original function of the fortress is identified as a late Roman military garrison post (*castellum*) in the borderline province of Scythia Minor, which also served the interior security control of the area. Nevertheless, little is known about its internal space planning and only remains of single buildings are assigned to the 4th c. AD phase.

A massive burned destruction layer was attested throughout the fortress. Most likely it is associated with an attack of the Huns in AD 442 or AD 447 (see Section I.2.1.), as inferred from the numismatic evidence from the site. Certain repairs of the defensive walls and re-building in the *intra muros* area took place in the second half of the 5th c. (Fig. IV.3.A.), invariably marked by an evident decline of the quality of the applied construction materials and techniques. Already by the end of the 4th c. AD the military fortress underwent a transformation into a civil semi-urban settlement and adopted the typical irregular dense planning of the internal space (Fig. IV.3.B.). Almost all of the buildings were constructed with stone-and-earth foundations and lower parts of the walls, clay or tile floors, mud-brick superstructure and upper floors, and covered with roof tiles.

The start of the final period of the late antique occupation is dated to the first half of the 6th c. AD. The Northern line of the defences was strengthened during two successive construction phases assigned respectively to the times of Anastasius I and Justinian I (Fig. IV.3.A.). Apparently, these changes were not a response to a particular hostile attack or to new damage of the fortress but rather they were a well-planned action for enhancing the military functions and internal layout of the settlement. New buildings were erected inside the fortress, and often the existing ones were divided into several smaller inner rooms (Fig. IV.3.B.), which indicates an overall increase of population and the number of households. As a result of these renovations the terrain of the site was levelled and raised, and street pavements laid in many areas of the settlement, pointing to a general improvement of the habitation standards. With great
certainty this period of the Odartsi site can be interpreted as an episode of Justinian’s programme, dated to AD 551-559, for reinforcement of the Lower Danube region and for restoration of the defensive systems in Scythia Minor (see Section I.2.1.). According to the numismatic data from the site, the 6th c. is a period of economic growth for the settlement, with a culmination of this relative prosperity under the reign of Justinian’s successor – Justin II (565-574). The fortress survived undisturbed the turbulent decennia of the 6th c. (see Section I.2.1.). In the beginning of the 7th c., however, a devastating fire covering the entire space marked the end of the early Byzantine occupation. The latest coin found at the site was struck in AD 602-610; the eventual destruction of the site was possibly caused by the raid of the Avars and the Slavs in AD 615.

An early medieval Bulgarian settlement emerged in the ruins of the Byzantine fortress in the end of the 8th – beginning of the 9th c. Numerous buildings were dug into the late antique layers or even reaching the levels beneath them (Fig. IV.2.); this settlement expanded outside the fortified area and existed until ca AD 1030. Slightly later, by the end of the first half of the 11th c., a necropolis of the Pechenegs developed to the North of the hill, partly covering the intra muros space as well.

The long site history of Odartsi is the reason for its quite complex stratigraphy. The late antique layers are significantly disturbed by the medieval buildings which hampers to a great extent the attempts to reconstruct the original context of the finds. At the same time, it needs to be pointed out that the joint Bulgarian-Polish programme was focused mostly on exploration of the early medieval settlement as part of a wider research strategy for studying the material culture of the Southern Slavs (Dončeva-Petkova et al. 1999; Kurnatowska and Mamzer 2007).

Therefore, many aspects of the late antique occupation remain only partly clarified and interpretations are often based on comparisons, historical reasoning, and indirect evidence. For instance, the important question about the local small scale secondary glass working at the site is not sufficiently spelled out. According to the field documentation, numerous lumps of ‘glass slag’ were found in the ground floor space of tower 4, tentatively interpreted as traces of a glass workshop activity (S. Torbatov
pers. comm.). It is quite likely that small scale production of glass objects took place in the settlement but unfortunately no finds from tower 4 were available for the present project. The date of these remains of supposed glass working is also unclear (possibly 6th c.?), although it was found that tower 4 suffered from a devastating fire during the last phase of the settlement and was no longer maintained (S. Torbatov pers. comm.).

IV.1.2. The vessel glass assemblage and sampling

The assemblage of glass fragments from Odartsi available for the present study consists of ca 135 pieces in total\(^\ast\), and nearly half of them were analysed (i.e. 60 samples, see Section II.2.1.2.; Table II.2.). All of the glasses, except two finds (ODR 42 – a flat window pane fragment, and a flat undiagnostic burnt piece, not sampled) represent various shapes of oil lamps and tableware, and only a few containers were identified. Furthermore, at least 70 fragments belong to the Isings 111 type (stemmed goblets; 32 of them analysed), which seems to be the dominating vessel at the site, comprising at least 50% of the entire assemblage. The materials come mostly from the areas excavated by the Bulgarian team, but also a few finds from the Polish fieldwork in the Western Sector are included here.

Certain issues need to be addressed in regard to the Odartsi vessel glass assemblage. Firstly, its study, as part of the present project, was conducted long after the fieldwork. The fragments available at present are possibly only a fraction of the whole mass of glass excavated at the site, but earlier preliminary selections have reduced the assemblage to ca 135 pieces, leaving aside the undiagnostic fragments\(^\ast\). Furthermore, to establish the relation between the glass finds and particular and comprehensive site stratigraphy was quite difficult or even impossible, mostly due to the distance in time between the excavations and the post-excavation research. It is hard to link the glass fragments to their original contexts of discovery, except for very few single cases (e.g. ODR 8, ODR 28, ODR 30, and ODR 47, found together in Building

\(^\ast\) The finds from Odartsi are part of the collection of the Regional Museum of History in Dobrich.
\(^\ast\) No information about these selections was available at the time when the present project started.
II, with a coin dated to AD 570-571; ODR 48 found in Building XIV together with a coin dated after AD 546/547; S. Torbatov pers. comm.). No detailed information was available for the Polish excavations; thus making the publications of the glass from the Western Sector of limited use for the objectives of the current project* (cf. Dekówna 1985; but also Dekówna and Dymaczewska 2014; Kucharczyk 2014; Salamon 2014).

Finally, the nature of the site, with its disturbed layers and, most of all, with the incomplete or even only partial field research done on the late antique buildings, may explain the unusual underrepresentation of certain 5th c. glass groups (see Section IV.2.1.). An explanation of the virtual absence of chemical glass compositions typical for the 4th c. in Odartsi (apart from an ‘outlier’ – ODR 51) is beyond the remit of the present study, since too diverse explanations are possible here.

All these peculiarities of the Odartsi glass significantly influenced the ways this site assemblage was approached and sampled. At first, the overwhelming majority of finds was identified as representative of the usage of glass during the final period of the settlement (see Section IV.2.2.). This was possible thanks to the preliminary results from the study of Dichin glass (Rehren and Cholakova 2014). With no detailed stratigraphic evidence, but knowing that the end of the early Byzantine occupation of Odartsi was caused by a sudden and violent devastation, this range of latest glasses (both as morpho-typology and composition) is seen as a ‘snapshot’ of the situation around AD 610-615. The earlier (and possibly later) glasses were identified through a comparative approach only, without reliance on the scarce information about their contexts of discovery. Due to the apparent disproportion which may not be representative, no attempts were made to juxtapose different groups in terms of quantities. The Odartsi assemblage was hence studied as a collection of preserved fragments per se, without relating its interpretation to the different aspects of the site history.

* The series of publications from 2014 present a rim fragment from Odartsi, possibly of a stemmed goblet, with remains of an inscription. The vessel is dated to the 6th c., and is defined as being probably of Egyptian origin (Kucharczyk 2014; Salamon 2014). In terms of its chemical composition this find matches the main group of Odartsi glass discussed below (cf. Section IV.2.2.; Dekówna and Dymaczewska 2014). These publications appeared when the writing up of the present Chapter IV was already at an advanced stage. Therefore, it was not possible to fully incorporate their conclusions into the present overview of the Odartsi assemblage.
Therefore, the sample selection in this case had its particular objectives. It was aimed mostly at an investigation of the 6th c. composition and the likely link between this chemical makeup and specified vessel morphology. Stemmed goblets Isings 111 constitute more than 50% of the samples, initially grouped with attention to their visual characteristics: the glass tint (greenish and yellowish, with some exceptions or blurred hues or strongly coloured dark-blue), and the shape of the stem (plain, or with a ball knop). Following this preliminary and quite formal sorting, representative samples were selected from each group in order to test whether any correlations to the glass chemical composition can be established. Furthermore, vessel fragments of a specific manufacture, made of olive-yellowish glass were tentatively recognised as HIMT composition, and nearly all of them were sampled to test this eyesight identification*. Finally, certain other samples were selected to represent vessel shapes which appear as consistent morphological series in Odartsi (i.e. oil lamps with tubular bases, pushed-in bases, small flat vertical handles – Fig. IV.5.), particular exceptions, and a single window pane fragment (Fig. IV.13.). As previously explained, 60 samples from Odartsi were analysed by LA-ICP-MS and EPMA, within four analytical runs in total, with a prevalence of the number of LA-ICP-MS analyses (Table II.2.).

* Most of the HIMT fragments were sampled in the very beginning of the analytical work, together with the samples from Dichin, and their labels have the abbreviation ‘G’ instead of ‘ODR’.
IV.2. Groups in the Odartsi assemblage

The analysed fragments from Odartsi are relatively uniform in terms of techniques of vessel manufacture and glass colour. Almost all the vessels are free-blown, with only a few exceptions of mould-blown (ODR 45) and optic-blown patterns (ODR 9, ODR 26, ODR 33). The presence of additional decoration is quite rare, and when applied it consists of simple blue blobs and trails, and very thin wheel-abraded lines. Some fragments are made of glass whose visual appearance has been intentionally modified using specific additives: colourless, nearly decolourised with yellowish tint, yellow-olive/ yellow-brown, cobalt-blue. However, the majority of the vessels are made of glass which appears just naturally coloured, mostly in various green tints, due to the mineral impurities in the glassmaking sands used for its melting.

The initial grouping of the Odartsi assemblage based on macroscopic archaeological criteria only, such as vessel morpho-typology and techniques of manufacture outlined several bigger groups: vessels with outsplayed cracked-off rims (assumed HIMT composition), stemmed goblets Isings 111, oil lamps with tubular bases, pushed-in bases of cups/ lamps (?), certain single examples (fire-rounded rims: with blue trails, or plain rims of flasks) and outliers. This working-stage classification was subsequently refined and corrected by integration of the compositional evidence as it emerged (see Section II.1.2.). The analytical results showed that the majority of the samples belong to the 6th c. composition (as already attested in the Dichin assemblage), and hence some of the initial morpho-typological groups were combined into a single bigger production group (43 samples). The HIMT identification of the vessels with cracked-off rims was confirmed, forming another distinctive group in the Odartsi assemblage (10 samples). The remaining seven samples are considered as ‘Varia’ – some of them belong to the 5th c. Mn-decolourised composition, and the rest are exceptions or single cases showing particular compositions.
The following sections present the glass vessel groups in the Odartsi assemblage as defined by their artefact characteristics and chemical composition. The data obtained for Odartsi is also discussed in the context of the similar finds from Dichin and Serdica, and when appropriate it largely refers to parts of Chapter III and Chapter V.

**IV.2.1. Beakers with cracked-off rims – yellow to dark-olive/ brown glass (HIMT composition)**

This category was discussed more extensively as part of the section about Dichin (see Section III.2.3.). The fragments from Odartsi have exactly the same macroscopic characteristics and compositional makeup, confirming the existence of a distinct and more or less internally consistent production group in the Lower Danube region. The overall number of yellow to dark-olive glasses from Odartsi available for this study is 14, and ten of them were analysed (Appendix B.2.2.). Unlike the respective group from Dichin, a more limited range of vessel shapes is found at Odartsi, with a striking domination of one single type. At least nine fragments (and most probably 11 in total) belong to the same type of tall beakers with cracked-off outsplayed rims and concave bases documented in Dichin (Fig. IV.4., G7, G 8; cf. Fig. III.8., G 13, G 16, G 37). The shape is comparable to Isings 106b-c and identical with Foy’s Form 13d from Southern France (Foy 1995). Most of the examples from Odartsi have no preserved decoration, except single cases of applied dark-blue blobs and very thin wheel-abraded horizontal lines (Fig. IV.4., G 43). The base fragments demonstrate a quite standardised size and a constant lack of pontil marks (Fig. IV.4., G 6, ODR 41). At the same time, the variations of wall thickness, colour tint, and chemical composition suggest that these beakers are not a one-off output of a single workshop but they belong to a quite uniform and widespread mass-production tradition (cf. Sorokina 1971, Fig. 1.8.). The finds from Odartsi must have been manufactured within the studied region, given their overall popularity and moderate quality, and likewise the similar vessels from Dichin.

* Samples G 5 and ODR 43 come from a rim and a wall fragment collected from one and the same spot within the site; the analytical data show that they may originate from a single production event or a single beaker.
Fig. IV.4. Odartsi – fragments of beakers with cracked-off rims and vessels made of HIMT glass composition, probably late 4th – first half of the 5th c. (?). Note the traces of intentionally chipped-off wall breakage of G 10. A. Honeycomb cup from the N. F. Bijnsdorp collection – this vessel type is a possible reconstruction of the wall fragment ODR 45 (after https://ancientglass.wordpress.com/page/13/ – accessed August 2015).

The remaining three samples in the present group come from different vessel shapes (Fig. IV.4.). A rim fragment of a deep cup (G 9) is distantly comparable to G 12
from Dichin and quite probably part of the same secondary glass working tradition in the region, similarly to the tall beakers mentioned above.

A small wall sherd ODR 45 is the only example in the current dataset of cup Isings 107a with low-relief honeycomb pattern produced by mould-blowing – a type also known as Wabenbecher (Fig. IV.4.A.). These vessels are popular but still not too abundant in the Eastern Balkans, some of them also found in secure 4\(^{th}\) c. contexts in Southern Bulgaria (Cherneva-Tilkian 1995, Fig. II.16; Shepherd 1999, n253-254; Minčev 1988, n39). More generally, the Isings 107a mould-blown cups were widely distributed during the 4\(^{th}\) – 5\(^{th}\) c. (e.g. Foy 1995, Form 13e; Sorokina 1973, Fig. 2.10-18; an overview in von Saldern 2004, 318-319), having certain varieties, regional specifics, and not necessarily made of yellow-olive glass only (e.g. Whitehouse, 1997-2001-2003, vol. 2, n606). The fragment from Odartsi may be very tentatively assigned to a possible influx of such imports from East Mediterranean (?) secondary workshops to the broader Black Sea region (cf. Golofast 2009, 304), even though the chemical composition of ODR 45 does not differ from the rest of the yellow-olive glasses (see Section III.2.3., cf. Fig. III.9.).

Finally, a base fragment with high solid ring is added to the present group because of the visual appearance of the glass (Fig. IV.4., G 10). There is not sufficient evidence for reconstructing the entire vessel shape (a large dish/plate?) since the fractured edges of the walls are carefully chipped-off and slightly smoothened. This suggests that the intact heavy base could have been re-utilized even after the initial breakage of the original vessel. Interestingly, very similar bases with secondary re-shaping are found in Crimea (Golofast 2009, Fig. 14.22-24), underlining the common trends in glass vessel usage in the Black Sea region. Such heavy solid ring bases are known from other parts of the Empire as well (e.g. Foy 1995, Form 10c), including some made of probably identical olive-green glass (Faiers 2013, n202).

No detailed information is available about the context of discovery of the fragments in the present group from Odartsi, and at least half of them were recorded as unstratified finds. However, considering the overall development of the settlement, the yellow-olive glasses should not be related to the 6\(^{th}\) c. phase of the site.
Hypothetically, they could originate from the destruction layers from ca mid-5th c. (see Section IV.1.1.) and are generally representative of the glass from the late 4th – first half of the 5th c. Such a tentative chronology would be in good agreement with the materials from Dichin.

The analytical data confirmed the preliminary visual assessment that the yellow-olive fragments belong to the HIMT primary glass group. This composition was thoroughly presented earlier (see Section III.2.3.). It is interesting to point out that the samples from Odartsi represent nearly equal proportions of both sub-groups of this makeup – ‘HIMTa’ displaying extreme iron oxide values, and ‘HIMTb’ with moderate levels of this compound. A slight prevalence of ‘HIMTb’ (Appendix B.2.2.) is seen among the Odartsi glass, with the honeycomb cup ODR 45 and the large base fragment G 10 (both exceptional and possibly imported vessels) belonging to this sub-group. Such internal distribution of the HIMT group is in stark contrast to Dichin, where only a single sample (out of 16 in total) is assigned to the ‘HIMTb’ sub-group. Nevertheless, drawing further conclusions from this pattern may not be realistic since the fragments from Odartsi represent a chance site collection rather than a systematic archaeological assemblage.

IV.2.2. Stemmed goblets and oil lamps – various glass tints (6th c. composition = Série 2.1.)

The present group comprises the overwhelming majority of the glass finds from Odartsi, and hence the majority of samples (43 samples out of 60 in total; Appendix B.2.7.). The reasoning for their incorporation as a single entity within this integrated classification is similar to the logic of formulation of the otherwise archaeologically diverse group of the 5th c. Mn-decolourised composition (see Section III.2.4.). The initial sorting of the finds according to their macroscopic artefact characteristics (i.e. vessel morpho-typology, glass colour, etc.) outlined three distinct groups in Odartsi assemblage – stemmed goblets Isings 111 with various colours, oil lamps with tubular bases, and pushed-in bases (most probably of lamps). However, the analytical results demonstrated that despite this diversity of glass tints and vessel functions/ shapes no
separation is seen in terms of chemical composition. Therefore, these three different archaeological units (and a few other fragments) were combined into a single bigger group based on the characteristics of production (i.e. the common glass composition and vessel manufacturing techniques). It is believed that possibly all of the finds in the present group from Odartsi belong to the repertoire of secondary workshops situated within the Lower Danube region. In this way, the observed variety of shapes is a logical representation of the production ranges of these ateliers (similarly to the vessels made of 5th c. Mn-decolourised composition in Dichin), rather than a sign of diversity of technological styles.

Isings 111 vessels were mentioned earlier as almost the only glass type to be present in the 6th c. contexts in Dichin (see Section III.2.5.). The bigger part of the Odartsi assemblage is assigned *en masse* to the final period of the site (6th – very early 7th c., see Sections IV.1.1. and IV.1.2.), and it demonstrates a very similar pattern of significant prevalence of stemmed goblets. Accordingly, the largest section of the present group consists of Isings 111 (Fig. IV.5.). As mentioned above, at least half of all the Odartsi glass fragments were identified as goblets (at least 70 individual sherds, almost all of them from the lower part of the vessels), and the sampling of the assemblage was aimed at their detailed study. Analyses were done on 32 selected finds, and 29 of them belong to the present group*.

The stemmed goblets from Odartsi reinforce the observation made on the Dichin finds that no single and consistent glass colour is related to this group, and the hues vary within broad ranges of yellowish to brown and bluish to dark-green (Fig. IV.5.). All the vessels are made of a single gather of glass (‘folded stem-cum-foot’ – Stern 2012, 52), and two varieties of the main type are present in the Odartsi assemblage – goblets with a ball knop on the stem, and goblets with plain stem. Still, firm statements about the upper part of the vessels are not possible since no rim sherds were available for study of the whole shape. The fragment with the highest preserved profile is ODR 20 (Fig. IV.5.). However, the pontil marks on all the bases indicate the shaping of fire-rounded rims of the goblets. At least some of them had

* Stemmed goblets ODR 1, ODR 11, and ODR 30 are discussed separately in Section IV.2.3. because they differ compositionally from the main group of Isings 111 outlined here.
small looped handles, allowing the vessel to be suspended and used as oil lamp (e.g. Fig. IV.5., ODR 50). The insignificant number of preserved handle fragments (only five) though suggests that possibly most of the vessels had plain walls. Additional decoration such as slight optic-blown ribs is present on two fragments only (ODR 9, ODR 26 – cf. Antonaras 2014, Fig.12.16.). In summary, the stemmed goblets from Odartsi seem to represent a quite functional and versatile vessel type, with very little or no decorative features, which was certainly used as lighting equipment (suspended or placed on a smooth surface), and, depending on the context, perhaps as drinking tableware as well.

Stemmed goblets have a long production tradition in the Mediterranean, the beginning of which was generally dated back to the 4th c. according to the main outline of Roman glass vessel morpho-typology (Isings 1957, 139-140). Such an early date is suggested for some finds from the Lower Danube area (e.g. Turno 1989, Olczak 1995, 62-63). However, more recent studies take into account the techniques of manufacture combined with stratigraphic evidence, and point out that goblets made of a single gather of glass (‘stem-cum-foot’) ‘do not predate the mid-5th c. in the East or in the West’ (Stern 2012, 53; cf. Hayes 1975, 84), or the start of their production is dated even later∗. The ubiquity of these vessels in the 6th – 7th c. contexts around the Mediterranean and in the Black Sea region is a commonly observed phenomenon (cf. Whitehouse 1997-2001-2003, vol. 2, 118; Foy 1995, Form 23; Golofast 2009, 316; Fünschilling and Lafli 2013, 61), and the overall chronology of the current dataset is in good accordance with it.

Certain details of the goblets’ forms, mostly of their stems, have been taken as criteria for developing numerous typological schemes within the main vessel shape (e.g. Jennings 1997/1998, 116-117; Dankova 1993, 82-84; Olczak 1995, Fig. 1; Dussart 1998, 115-121; Dekówna 1985, Fig. 1; Çakmakçı 2009). At the same time, it seems quite possible that the morphological variability of the goblets from Odartsi (e.g. not standardised sizes of the foot discs, along with variable thickness, height, and type of blockage of the stem, etc.) was partly driven by unintentional differences between

∗ ‘…cannot have been produced earlier than the very late 5th c. and became widely used during the 6th c.’ (Fünschilling and Lafli 2013, 65).
Fig. IV.5. Odartsi – fragments of stemmed goblets Isings 111 and oil lamps made of 6\textsuperscript{th} c. glass composition, 6\textsuperscript{th} – early 7\textsuperscript{th} c. (?); partly after Cholakova \textit{et al}. 2015. A. Cup-shaped oil lamp from Histria – this vessel type is the suggested reconstruction of the base fragments with high central kick, e.g. ODR 54 (after Băjenaru and Bălțăc 2000-2001); B. Morphological range of the glass oil lamps from the 6\textsuperscript{th} c. Western Mediterranean (after Foy 2011).
individual workshops’ and craftsmen’ skills, or by varied attention to the manufacturing process rather than by deliberately followed different models. The only definitive style- and technology-driven differentiation among the goblets in the present dataset is found in the stem silhouette, which can be plain, or with a ball knop. Goblets with knops are interpreted as typical for the East Mediterranean tradition, which was replaced by the plain stem model from the second half of the 6th c. (Weinberg and Stern 2009, 148; Stern 2012, 54). Interestingly, the studied set of goblets from Dichin dated to ca AD 540-580 consists mostly of vessels with knops (cf. Fig. III.17.). The assemblage from Odarzsi which has a general terminus ante quem of ca AD 610-615 (i.e., it should be later than Dichin) contains only eight goblets with knops, out of 46 examples of preserved and identifiable Isings 111 stems. A similar prevalence of plain stems was found in the glass assemblage from Nicopolis ad Istrum (Shepherd 1999, 372), and also in the Serdica assemblage (see Section V.2.5.). However, a tentative explanation of the stem shape as chronological criterion should be considered with caution, at least in regard to the Lower Danube finds. The closest analogies of the Odarzsi goblets and lamps come from a large deposit of glass found in a Christian basilica in Histria/Istrus (in present-day Romania), on the Black Sea coast in the Northern part of the province of Scythia Minor (Băjenaru and Băltăr 2000-2001; Appendix A.1.). The deposit is securely dated to the very end of the 6th c. – early 7th c., or ca AD 613-614 at the latest and contains a variety of goblet fragments, both with knops and plain stems. Despite this morphological difference they all seem quite similar and standardised as vessel shape outline (Băjenaru and Băltăr 2000-2001, 487, Pl. VI-IX). Well-dated finds from Crimea also contradict the idea that the production of goblets with knops precedes the plain stemmed goblets (Golofast 2009, 317). Therefore, the conclusion of Fünfschilling and Lafli (2013, 66) that the diversity of such morphological features have little interpretative significance seems plausible, at least in chronological aspect.

The sampling of the Odarzsi goblets was aimed at identifying possible compositional distinctions between different morphological sub-types (i.e. stems with knops and plain stems), and between different glass colours (i.e. tints of yellowish-brown range and tints of bluish-green range). However, the analytical data
demonstrates a striking consistency of the chemical makeup across the macroscopical grouping. Furthermore, the refinement of the results shows an internal subdivision within the compositional group (Cholakova et al. 2015; see below the discussion of the analytical data) but it seems to be entirely geochemically driven, and the compositional sub-groups have no correlation to the macroscopically separated vessel sub-types. Hopefully, future research on Isings 111 from contexts with narrow dating would clarify whether a chronological sequence of different stem shapes could be established, or different but contemporaneous manufacturing styles co-existed in the overall repertoire of the secondary workshops in the Lower Danube region.

Finally, a short comment on the function of Isings 111 is necessary. Most probably these goblets were used both for lighting and as drinking vessels (Fünfschilling and Lafli 2013, 61; Olcay 2001, 86), and particular contexts of discoveries would be needed to provide more definite evidence for the one or the other. At the same time, a general trend for reduced (or even ceased) manufacture of common glass tableware during the 6th c. is evident in the present dataset from the Lower Danube. This process coincides with an increased diversity and development of the glass oil lamp shapes observed in the broader Mediterranean region (Fig. IV.5.B.; Foy 2011). Apparently, a range of changes must have contributed to this shift in the usage of glass vessels – e.g. changes in everyday dining habits, of interior architectural layout (both ecclesiastical and secular), of overall household traditions, etc. However, it is beyond the scope of the present project to continue further the discussion of such phenomena. A detailed comparative study of wider-scale assemblages of functionally related artefacts (i.e. glass stemmed goblets, clay lamps, pottery for serving and drinking, window panes) would be a promising way forward. In regard to the present dataset, a tentative interpretation of the stemmed goblets mostly as equipment for interior illumination seems plausible.

The remaining 14 samples in the present group come from a relatively limited range of vessel shapes, reinforcing the predominance of Isings 111 and the overall prevalence of glass used for lighting in Odartsi. Six fragments of oil lamps with tubular bases were sampled, out of ten available for the present study (Fig. IV.5., ODR 37, ODR 40, ODR 46, ODR 47; Appendix B.2.7.). All the lamps are made of green glass,
seemingly darker than most of the other vessels in the group due to their thicker walls – no sherds of rims were preserved and all the studied pieces come from heavier lower parts. Nevertheless, numerous parallels of this popular type suggest that the upper parts were bowl-shaped, with slightly expanded or narrowed openings (e.g. Olczak 1995, 51; Băjenaru and Bâltăc 2000-2001, Pl. I-III). Small marks of pontil attachment on all the tubular bases indicate that the vessels had fire-rounded rims. These lamps (with small loop handles or with plain walls) were a standardised mass-production, certainly used in combination with some kind of devices for suspending (e.g. Petcu et al. 2014), or placed in polycandela (e.g. Whitehouse 1997-2001-2003, vol. 1, n340). Lamps with tubular bases (also called stemmed lamps) are often found in East Mediterranean and Balkan contexts (e.g. Rehren et al. 2010, Pl.4.B; Drauschke and Greiff 2010, Pl.1.1) and they have a long tradition of usage and typological variations (Olçay 2001, Crowfoot and Harden 1931, Pl. XXIX). Within such diversity, the lamps from Odartsi demonstrate close similarities to the vessels from the Northern Black Sea coast, dated to the 6th – 7th c. (Žuravlev 2007, 231), confirming the general observation for common trends in glass vessel manufacture in the broader region.

Another homogeneous series of fragments in the present group consists of pushed-in bases with high central kick. Five of them were analysed (Fig. IV.5., ODR 54, ODR 33; Appendix B.2.7.), out of ten in total available for study. All the bases look quite uniform in terms of glass colour and production techniques, similarly to the lamps with tubular bases discussed above. At the same time, variations of the vessel sizes and chemical compositions indicate that most probably they come from a well-established production tradition but still not from a single workshop’s output. ODR 33 with optic-blown decoration of slight vertical ribs is a single example of different manufacturing style within the same tradition. No evidence is available for reconstruction of the upper parts of the vessels, except the pontil marks on all the bases which indicate the presence of fire-rounded rim edges and possibly handles. Similar pushed-in bases are known from various contemporaneous assemblages (e.g. Golofast 2009, Fig.14.1-7; Füünsching and Lafli 2013, Taf. 3). It seems that the high central kicks are not random features; they rather represent a consistent and intentionally repeated morphological trait. A likely interpretation of this peculiarity
may be related to the function of the vessels. Cup-shaped oil lamps with such concave bases are often recognised in the early Byzantine glass repertoire (Fig. IV.5.A.; e.g. form Isings 134; Cherneva-Tilkian 1995, Fig. II.17; Băjenaru and Băltăc 2000-2001. Pl. X.8). The wall fragment with loop handle ODR 50 mentioned in regard to the stemmed goblets could well be part of such a cup-shaped oil lamp used in combination with a suspending device (e.g. Olczak 1984). The high central kick could function as support for a cone-shaped metal wick-holder, placed on the bottom of the lamp (reconstruction in Foy 2011, Fig. 12.3). The particular functional role of the high pushed-in base (as opposed to purely decorative or random variations during vessel shaping) could be the reason for the uniform repetition of this morphological trait. Its distant typological development may be seen in later oil lamps with wick-tubes made of separate gather of glass, fixed on a similar high central kick at the bottom of the vessel (Keller 2010, Fig. 4.3; Crowfoot and Harden 1931, Pl. XXVIII.7-9). Such an interpretation is only tentative at the present stage of research but it seems very probable and would reinforce the conclusion about the predominant usage of glass vessels for interior lighting rather than as part of dining practices towards the end of Late Antiquity.

The last two samples in the present group are ODR 52 – a neck fragment of a flask, and ODR 53 – a vertical ribbon handle (Fig. IV.5., Appendix B.2.7). Their manufacture is very simple, with little attention to the details, and rough tooling marks on the flask rim. The handle is plain, lacking any ribs or serrated edges on its lower part, which are typical for the earlier Roman and late Roman jugs and bottles (cf. Fig. IV.13., ODR 51). Five more handles of the same type and size were found at Odartsi (not sampled), and this uniformity of numerous pieces could mean that containers (bottles?) of relatively small volume with two handles were used at the site, possibly acquired from secondary workshops within the neighbouring area of the settlement.

As mentioned earlier, there is only limited evidence of the exact contexts of discovery of the glass finds from Odartsi; hence, their dating is based mostly on indirect reasoning. Helpful indications come from the numismatic study (Torbatov 2002a) which showed that four samples in the present group – three stemmed goblets and a tubular lamp base – were found together with coins dated to the second half of
The devastating fire which marked the end of the early Byzantine settlement is dated to ca AD 610-615, and the approach preferred here is to consider the present group altogether as a late 6th c. – early 7th c. set of finds. Such a date is well-confirmed by the analogies with the Dichin glass, with similar assemblages with secure chronology from the province of Scythia Minor (Băjenaru and Bâltâc 2000-2001), and with the overall timespan of the chemical glass composition (Foy et al. 2003, 57-59).

The makeup of the present group is labelled as ‘6th c. composition’ on the basis of the results from Dichin assemblage where this is the only composition found in secure 6th c. contexts (see Section III.2.5.). As already pointed out, this makeup corresponds to a glass group outlined for the first time as ‘Série 2.1.’ in assemblages from Southern France and Northern Africa (Foy et al. 2003). The 6th c. composition is characterised by generally higher and also correlated concentrations of most minor oxides, compared to typical Roman glass and later Syro-Palestinian groups (e.g. Levantine I), but at the same time these concentrations are lower compared to HIMT glass. Such ‘intermediate’ characteristics and the wide ranges of variations for the two major oxides, commonly considered as diagnostic for compositional identification (i.e. alumina from nearly 2 to over 3 wt%, and lime from 6.7 to 9.7 wt% – Fig. IV.6.), result in certain discrepancies in the interpretations of this group when attested at different sites. The preliminary publication of the Dichin assemblage emphasised the similarity of the 6th c. glass to the earlier Roman blue-green glass, introducing the label ‘dirtier Roman blue-green glass’ but also pointing at an ambiguous resemblance of this glass to other known compositions (i.e. HIMT 2 and Group (Série) 2 – Rehren and Cholakova 2014, 92). The subsequent refinement of the data reinforced the identification with Série 2.1., and provided further evidence that this is a distinct primary group and not a variety of another main composition (Cholakova et al. 2015).

The following discussion presents an overview of the 6th c. composition (= Série 2.1. of Foy et al. 2003) based on the samples from the entire dataset of the project – the assemblages from Dichin, Odartsi, and Serdica. Unlike the other chemical groups commented upon so far, the 6th c. composition does not demonstrate immediately recognisable and striking characteristics (such as distinctively very high, or very low
Table IV.1. Average chemical composition of all the 6th c. glass samples in the present dataset (n=79; all oxides in wt%; only P2O5 in ppm). The iron-rich sub-group is characterised by increased values of Fe2O3, Al2O3, and P2O5, but slightly lower lime and manganese content (highlighted). See Appendix B.2.7. for detailed data.

values for major and minor oxides), but instead has overall moderate levels of the main compounds (Table IV.1.). Nevertheless, the magnesia and phosphate concentrations are at the higher end of the ranges typical for more common mineral soda glasses of Late Antiquity (the distribution of MgO is between ca 0.9 and 1.55 wt%). Iron oxide demonstrates similarly higher values of nearly 0.8 to 3.5 wt % and a separation of the samples in two sub-clusters with a slight gap between them at about 1.2 wt% Fe2O3. The same division in two sub-groups is evident for certain trace oxides (NiO, As2O3, V2O5), which have higher ranges for the samples with elevated iron oxide. However, the concentrations of titania are relatively constant, varying within narrow limits between 0.11 to 0.19 wt% (with a single exception of 0.23 wt%), and no separation is seen here. The titania range and the unusually ‘elongated’ outline of the

Fig. IV.6. 6th c. composition samples (= Série 2.1.) compared to the 5th c. Mn-decolourised composition (= Série 3.2.) from the present dataset. Note the position of the 5th c. intermediate sub-group partly overlapping with the 6th c. composition.
The iron-rich sub-group with different Fe$_2$O$_3$–TiO$_2$ ratio evident both in the samples from the Lower Danube region and from the Western Mediterranean. Fe$_2$O$_3$–TiO$_2$ scatter-graph are both among the defining characteristics of the 6$^{th}$ c. composition (Fig. IV.7.). Manganese has a wide spread of concentrations, from 0.2 to nearly 2.0 wt%. However, the typical values are higher than 0.7 wt% suggesting intentional addition of MnO as glass colour modifier despite the variety of hues resembling naturally coloured glass (Fig. IV.8.A.). Interestingly, strontium oxide is above the expected levels for common natron glass (e.g. Freestone et al. 2003, Fig. 3), with an average of about 800 ppm and reaching concentrations of approximately 1000 ppm in individual samples. Apparently, this compositional trait is another important diagnostic feature of the present group. However, it needs to be clearly said that its correct identification largely depends on the abilities of the particular analytical technique used (see Section II.2.1.4.; Fig. II.9.).

In addition to the finds from Southern France and Northern Africa studied by Foy and co-authors (Foy et al. 2003), the 6$^{th}$ c. composition (= Série 2.1.) is relatively well-recognised in a few more regions/site assemblages (e.g. recently in Gliozzo et al. 2015b; Schibille et al. 2016). A considerable (but still far from being predominant) presence of this group has also recently been found at three sites in Cyprus, tentatively
Fig. IV.8. A. 6th c. composition and 5th c. Mn-decolourised samples from the present dataset: comparison of the MnO levels and the different glass colour tints. Interestingly, almost all of the samples from both groups demonstrate a ratio MnO/Fe$_2$O$_3$<2, i.e. beyond the supposed limit for effective glass decolourising (Silvestri et al. 2008, 336). Note the increased iron oxide levels for the 6th c. sub-group, and its erratic but overall reduced MnO concentrations.

B. Comparative data of the 6th c. composition from published assemblages. Note considerably fewer samples in the iron-rich sub-cluster.
dated to the 6th c. (named HLIMT – Ceglia et al. 2015). The resemblance between the patterns of primary glass distribution in the Lower Danube region and Cyprus is unsurprising. It is consistent with the historical data about merging of Moesia Inferior, Scythia Minor, Cyprus, and a few other East Mediterranean provinces in the 6th c. into a single administrative unit, *quaestura exercitus*, most probably with unified fiscal and supply mechanisms (see Section I.2.1.). At the same time, the study on Cypriot glass assemblages emphasises the similarities of the present group to a range of approximately contemporaneous glass compositions attested across the early Byzantine Empire and beyond its frontier in Western Europe, suggesting that it is ‘a widely traded glass type’, most probably with Egyptian origin (Ceglia et al. 2015, 215, 218). However, a more cautious approach is preferred here, considering the difficulties when data from diverse analytical studies is compared, especially regarding the results for important diagnostic minor oxides in concentrations close to the limits of reliable quantification for particular techniques (e.g. SrO and P₂O₅ determined by certain electron beam or X-ray based methods). Thus, an additional but quite helpful reasoning for drawing parallels between the 6th c. composition (= Série 2.1.) and chemical glass groups found elsewhere is employed in the present discussion. It is based on juxtaposition between chronologically well-defined assemblages, from sites that belong to the same context of early Byzantine traditions.

For this, the 6th c. composition samples from the present dataset are concisely compared to the glass finds from only a few other sites/ regional assemblages and, on the other hand, to the 5th c. Mn-decolourised composition in an attempt to interpret the specifics and the internal sub-division of this group. Along with the already mentioned examples of Série 2.1. from the Western Mediterranean and the so-called HLIMT samples from Cyprus, the analytical data from Iustiniana Prima in present-day Serbia and Galeata near Ravenna in Italy are taken into account as reference points (Drauschke and Greiff 2010; Arletti et al. 2010a). These sites provide materials with secure date (at least terminus post quem: after AD 493 for Galeata and ca AD 535 for Iustiniana Prima) because their construction is linked to the historically well-documented building initiatives of Theodoric Amal, the Ostrogoth ruler of Italy in AD 493-526, and Justinian I (527-565).
Fig. IV.9. 6th c. composition and 5th c. Mn-decolourised samples from the present dataset: the trace oxide ratios reflect particular geochemical combinations in the glass-making sands which serve as markers or ‘fingerprints’ of glass compositions; the observed close similarity of both groups implies the use of related sand deposits from broadly the same region (see also Appendix A.3.).

In the original publications the samples from Galeata (window panes) and Iustiniana Prima (unworked chunks) were not recognised as identical with Série 2.1. due to the ambiguous compositional characterisation of the 6th c. glass and its nominal resemblance to the broader HIMT primary group. However, these glasses should be interpreted as belonging to the 6th c. composition* which has no direct geochemical affinities to HIMT chemical makeup. The dissociation of these two groups is confirmed by different ratios of certain major oxides (Fe₂O₃/TiO₂, MgO/TiO₂, Fe₂O₃/Al₂O₃ – Cholakova et al. 2015; Ceglia et al. 2015, Fig. 4) implying fundamental differences in the glassmaking sands used in both primary productions. Accordingly, the 6th c. composition is considered here as a distinct primary group but not a variety of HIMT glass; the latter also being typical mostly for the earlier 5th c. contexts in the Lower Danube region and elsewhere (e.g. Foy et al. 2003).

* Some of the samples from Iustiniana Prima may be tentatively linked to the 5th c. Mn-decolourised composition (= Série 3.2.) attested in the early 6th c. as well, due to their lower alumina values (Fig. IV.10.; see Section III.2.4.) but more detailed trace oxide evidence is necessary for such a conclusion.
Instead, the analytical results from the present dataset suggest an explanation of the 6th c. samples as related to the 5th c. Mn-decolourised glass (= Série 3.2) in terms of their sand geochemistry, and hence in their provenance. A range of compositional features allow both groups to be interpreted as closely linked but not entirely overlapping and not forming a straightforward continuum over time, i.e. still as two separate primary productions (Cholakova et al. 2015). The scatter-graph of alumina and lime concentrations indicates overall similarities but also complex changes in the glassmaking sand employed throughout the 5th – 6th c. (Fig. IV.6.). The discussion of the 5th c. Mn-decolourised composition from the Dichin assemblage introduced the intermediate sub-group as evidence for gradual internal shifts in sand makeup presumably within the same production locations/ sand deposit, which however does not mark a direct transition to the 6th c. glass (see Section III.2.4.). A similar pattern is seen in the trace oxide data that show partial overlap but still a certain discrete clustering of the 5th c. Mn-decolourised composition and the 6th c. composition (Fig. IV.9.). At the same time, the dissociation from the HIMT samples is definite when the same trace oxide data are placed in the wider context of other glass groups (see
Appendix A.3.). Such a conclusion is also supported by the correlation of alumina and iron oxide which is well-pronounced in the 6\textsuperscript{th} c. composition main group and shares a broadly identical direction with the 5\textsuperscript{th} c. Mn-decolourised samples (Fig. IV.10.), while the HIMT group displays a different pattern of these oxides (cf. Ceglia et al. 2015; see Section III.2.3., Fig. III.9.A.).

Summarising the arguments based on the analytical data, it becomes evident that the 5\textsuperscript{th} c. Mn-decolourised composition and the 6\textsuperscript{th} c. composition from the present dataset demonstrate a range of geochemical resemblances implying their common origin, i.e. most probably utilisation of two neighbouring but still distinct sand deposits. Remarkably, the vessel shapes and manufacturing techniques of both these groups also display a certain gradual continuity (see Appendix A.2.), reinforcing the suggested link between the main glass compositions of the 5\textsuperscript{th} and the 6\textsuperscript{th} c. at the level of the secondary glass working in the Lower Danube. Nevertheless, the internal evolution of the 5\textsuperscript{th} c. Mn-decolourised composition attested in its intermediate sub-group marks probably a (localised?) deterioration of the glassmaking sand. This may be due to some mineral (apatite-deriving ?) contamination leading to correlated increase of SrO and P$_2$O$_5$ (Fig. III.15.A.) which, at the same time, does not mirror the complex sand adulteration markers of the 6\textsuperscript{th} c. composition.

The possibility to determine similarities between both groups has important implications regarding their interlinked provenancing, while the understanding the differences between them would shed light on the dynamics and transformations in primary glass making in Late Antiquity. It was already demonstrated that overall higher levels of alumina, lime, and almost all sand-deriving oxides differentiate the 6\textsuperscript{th} c. composition from 5\textsuperscript{th} c. Mn-decolourised glass (Fig. IV.6., Fig. III.15.C.). In terms of interpretation, this denotes a shift to a production based on sand deposits with higher amounts of various mineral inclusions, i.e. to a silica source of more moderate purity and lower quality. It is not possible to specify the reasons for such a choice of the main raw material for a large-scale primary glass centre, such as the producer of the 6\textsuperscript{th} c. composition. A likely (but not only) explanation might be gradual a depletion/deterioration and final abandonment of the purer (or, more easily accessible) sand accumulations which were in use prior to the 6\textsuperscript{th} c., as suggested by the intermediate
sub-group of the 5th c. Mn-decolourised glass (see Section III.2.4.). Access to regular fuel supplies may have also played role in this transition in the primary production.

In any case, the detailed comparison of both main compositions shows that this is not a case of mere gradual shift in the geological parameters of available natural deposits but an instance of conscious and deliberate change of both the production location and technology. Apparently, the empirical knowledge of the ancient glassmakers allowed them to recognise the altered sand makeup and to adjust their recipe accordingly, in order to counteract the lower quality of the new silica source. The 6th c. composition features considerably higher levels of manganese (ca 1.1-1.8 wt% MnO in the main group) compared to the 5th c. Mn-decolourised glass (ca 0.5-1.0 wt% MnO in the main group – Fig. IV.8.A.). The same high MnO values are found in the comparative published assemblages of the 6th c. glass (Fig. IV.8.B.). At the same time, the data from the Lower Danube tentatively characterise this difference as a kind of step-change rather than a continuous transition. Manganese is one of the commonly used additives in ancient and later glass industries intended to decolourise/ modify/ improve the appearance of the melt, and its introduction at the stage of primary glass making is generally acknowledged (e.g. Freestone et al. 2000, 71). At certain levels it can neutralise the glass colour resulting from sand impurities (iron oxide). However, the effect of added manganese depends not only on the amount used but also on more complex aspects such as oxidation state/ type of MnO source, and not least, on certain secondary alterations arising from fluctuations in the redox conditions during (repeated) recycling.

The diversity of the glass colour tints within the 6th c. composition group of vessels (cf. Fig. IV.8.A.) is most probably a result of all these factors combined with varying iron oxide contents. The 6th c. production formula with nearly twice higher amount of manganese than used previously (relative to the overall amount of sand in the batch) may have had a certain causal relation to the shift of the preferred MnO-containing ingredient. Alternatively, other reasons such as unavailability of particular geological MnO sources lead to the introduction of a new, perhaps more heterogeneous (less efficient?) raw material. The data from the present research suggest a positive correlation of manganese and strontium oxide in the 6th c.
Fig. IV.11. A. 6th c. composition samples from the present dataset compared to the data from Galeata and to 5th c. Mn-decolourised samples. Note the lack of correlation between SrO and MnO in the earlier composition suggesting that manganese does not introduce additional strontium oxide. B. 6th c. composition samples compared to the main Mn-containing groups from the present dataset (HIMT and 5th c. glass) and a virtually Mn-free composition (HIT). BaO levels characterise the added manganese and tentatively indicate different geological sources of MnO. Note the low BaO content of HIT composition, presumably coming from mineral impurities in the glass-making sand. Sample G 10, HIMTb composition from Odartsi is omitted in the graph due to its too high BaO content (ca 3150 ppm; MnO 1.73 wt%).
composition, confirmed by other published examples (Galeata finds and Série 2.1.
from the Western Mediterranean) but hardly visible for the earlier 5th c. Mn-
decolourised glass (Fig. IV.11.A.)*. It is accepted that levels of strontium in the natron-
based glass are mostly linked to the nature and origin of lime; higher Sr values (up to
cia 500 ppm elemental Sr = ca 590 ppm SrO) are expected for calcium carbonate
deriving from sea shell in the sand (Wedepohl and Baumann 2000, Freestone 2008, 90-
91 – in glasses ‘...containing between 4% and 10% CaO’). However, the 6th c. glass has
even higher concentrations, and their link to MnO implies that a certain further
quantity of SrO was introduced to the batch as a geological contamination of the Mn-
bearing additive. Manganese-rich minerals with significant amounts of strontium are
known (e.g. strontiomelane with approximately 9-13 wt % SrO – Meisser et al. 1999),
and could have been present in the raw material used by the glass producers as new
recipe ingredient in the 6th c. Significantly, the high MnO values in HIMT glass do not
lead to elevated SrO levels (Cholakova et al. 2015, Fig. 8). Therefore, high levels of SrO
correlated to high MnO are an important diagnostic feature of the 6th c. composition, a
discriminator for its correct identification. They likely represent an accumulation of this
oxide coming from two different starting substances in the glass melt (i.e. from sand/
lime, and from the colour-modifying additive). This results in unusually high levels
(average values of SrO: 812 ppm in the current dataset; 790 ppm in Série 2.1. of Foy et
al. 2003; 900 ppm in Galeata samples of Arletti et al. 2010a), which have no known
parallel among the rest of the natron glass compositions of Late Antiquity.

At the same time, the disconnection from the raw material sources used in the
5th c. is evident when MnO levels are compared to barium oxide, another commonly
known impurity in geological manganese deposits (Fig. IV.11.B.). The main group of 5th
c. Mn-decolourised samples demonstrates well-correlated BaO and MnO
concentrations, suggesting a relatively high content of barium in the added
manganese-bearing material. HIMT glass from the present dataset has less
pronounced correlation of both oxides but somewhat erratic BaO values, including
quite high levels in individual samples. Previous studies have interpreted the link

* The elevated SrO in the 5th c. Mn-decolourised intermediate sub-group is more likely related to
variations in the glassmaking sand composition rather than to the Mn-introducing ingredient (see
Section III.2.4.).
between BaO and manganese values as being due to the introduction of certain amounts of psilomelane, a Mn-containing mineral with considerable levels of BaO (Silvestri 2008; Arletti et al. 2010b; Gallo et al. 2013). The 6th c. composition also features a slight increase of BaO in some of the samples with higher manganese which may well be due to a minor content of this impurity in strontiomelane mineral. Thus, the MnO–BaO scatter-graph demonstrates a likely difference between the 5th c. compositions and the later glass group (Fig. IV.11.B.). Admitting the uncertainty of these arguments due to a lack of detailed knowledge about the Mn-sources exploited in antiquity, a tentative conclusion about possible change to a new source of additive in the 6th c. composition primary production still looks plausible. Interestingly, the trend-lines of both varieties of this group share the same direction, implying that the same kind of Mn-bearing material was used for the whole range of this glass making. This would indicate relatively steady raw material procurement over the timespan of the 6th c. primary production, which is at the same time different from the Mn-source used in the earlier composition.

Another important characteristic of the 6th c. composition, compared to the earlier 5th c. Mn-decolourised glass comes from trace oxides indicative of glass recycling. It was pointed out earlier that there is little or even no evidence of indiscriminate cullet reuse in the 5th c. samples (see Section III.2.4.). Remarkably, the 6th c. composition samples demonstrate much higher levels of metal oxides linked to glass colouring which, in trace concentrations, signify the inclusion of a certain amount of coloured pieces in the batch (Fig. VI.4.). The implications of this data will be discussed in detail later, in regard to the different levels of distribution networks (see Section VI.3.2.2.). However, certain aspects need to be mentioned here as well.

The concentrations of antimony oxide in the 6th c. samples vary within an approximate range of 20-770 ppm Sb$_2$O$_3$, while this contamination is virtually absent in the earlier 5th c. Mn-decolourised glass (Fig. IV.12.). Antimony oxide is naturally present only in negligible quantities in the glass-making sands (Brems and Degryse 2014, 79), and can be introduced to the melt either as intentional and distinct additive (aiming to decolourise or opacify), or unintentionally through re-melting of Sb-containing pre-existing glass. The levels of Sb$_2$O$_3$ in the 6th c. samples from the Lower
Fig. IV.12. 6th c. composition samples from the present dataset compared to the data from Galeata and the 5th c. Mn-decolourised composition: A. No link between antimony and lead oxides concentrations is evident suggesting the likely presence of diverse sources of contamination; note the virtual lack of Sb$_2$O$_3$ in the earlier 5th c. Mn-decolourised glass (only samples from Dichin vessels and Serdica chunks plotted); B. The iron-rich sub-group of the 6th c. composition seems to mark a relative decrease of the Sb$_2$O$_3$ content. Note the position of two samples from the 5th c. intermediate sub-group (both Isings 111 stemmed goblets) with slightly elevated antimony concentrations.

Danube (average of ca 160 ppm) are far below the concentrations of its deliberate use, which are in the range of several thousand ppm. Similarly, low trace concentrations were found in the other examples of the same composition (Sb$_2$O$_3$ ca 130 ppm in Série
2.1. – Foy et al. 2003; ca 200 ppm in Galeata – Arletti et al. 2010a, Fig. IV.12.A.; ca 360 ppm in Iustiniana Prima – Drauschke and Greiff 2010). Apparently, traces of antimony oxide are a constant compositional feature of this glass group, and hence one of the diagnostic criteria for its identification. Remarkably, the present dataset contains no analytically proven Sb-free examples of this group, and the same is valid for Série 2.1. and the Galeata samples. Such concentrations could only result from re-melting Sb-containing glass as part of 6th c. composition batches, which represents a stark technological contrast to the earlier 5th c. Mn-decolourised glass samples, only two of which have more than a few ppm Sb$_2$O$_3$ (Fig. IV.12.B.).

The reappearance of antimony oxide in the 6th c. glass cannot simply be considered as incidental, and therefore it needs to be interpreted. The technology of Sb-decolourising is generally seen as an earlier Roman tradition (cf. Sayre 1963). Some vessels made of pristine Sb-decolourised glass are occasionally known in late antique contexts (see Section V.2.3.) but not as late as mid-5th – early 7th c. The recycling of Sb-containing vessel cullet in the secondary workshops of the Lower Danube seems characteristic mostly for the late 3rd – 4th c. production (see Section V.2.6.). It disappears in the 5th c., probably due to the exhaustion of the available volume of Sb-decolourised cullet in regional circulation, resulting from the more general downturn of the primary Sb-decolourised glass production.

Therefore, instead of Sb-decolourised vessel cullet, re-melting mosaic glass tesserae seems a more plausible source of Sb$_2$O$_3$ in the 6th c. composition (cf. Henderson 1995). Antimony oxide was commonly used as opacifier in Roman and late antique tesserae production, most often in conjunction with colourants (e.g. Paynter and Kearns 2011; Silvestri et al. 2012). However, no clear correlation of antimony oxide to any of the glass colouring metals is found in the 6th c. composition (Fig. IV.12.A.), probably due to the diversity of the re-melted glasses and the randomness of their addition to the batch.

Reuse of mosaic tesserae is a well-known technological practice in post-antique secondary glass object manufacture. It is explained as a result of lack or shortage of fresh raw glass supplies, and in some cases is clearly detached from the stage of
primary glassmaking (e.g. Schibille and Freestone 2013; Freestone and Hughes 2006). Quite likely, similar reasons could have caused the re-melting of tesserae in the secondary glass workshops in the Lower Danube region towards the end of antiquity, along with other types of coloured cullet added to the 6th c. composition melts (see Section VI.3.3.2.).

Nevertheless, another technological possibility should also be considered, namely incorporation of pre-existing glass (including certain amounts of Sb-opacified mosaic glass) in the batches of primary glass-making, as recipe ingredient intended to facilitate melting of the starting raw materials*. This explanation was first suggested for Série 2.1., based on the fact that unworked chunks also have elevated concentrations of these recycling indicators (Foy et al. 2003, 46). The 6th c. composition chunks from Serdica demonstrate increased Sb$_2$O$_3$ levels as well, even though it cannot be definitely stated whether they represent fresh unworked glass or secondarily contaminated discards left behind from re-melting in the local workshops (see Section VI.1.1.1.).

Another indirect argument supporting the interpretation of cullet addition (traceable due to Sb-opacified mosaic glass) at the stage of primary glass production comes from a comparison of the site/ regional assemblages in a wider socio-economic aspect. As mentioned earlier, all the examples of 6th c. composition discussed here as analogies of the finds from the Lower Danube have significant trace concentrations of Sb$_2$O$_3$. Ordinary vessel manufacture from mixed (chance?) batches of clean primary glass, locally collected cullet, and scavenged tesserae would not be surprising in 6th c. Serdica – a provincial town with declining and strongly regionalised economy, not far away from the troubled Northern frontier of the Empire. However, a nearly identical glass composition, with similar levels of contamination is seen in Galeata (Fig. IV.12.A.), as window panes used in the bath sector of a luxurious villa complex built for the court of the Ostrogoth ruler of Italy, Theodoric Amal, one of the most powerful figures in the late 5th – early 6th c. history of the Mediterranean. There are no reasons to suppose a shortage of fresh primary glass supplies to the region of Ravenna which would trigger

---

* Theoretically, this may have had a certain positive impact on the fuel consumption, and therefore on the overall management of the production resources.
active reuse of locally available mosaic glass. Furthermore, even if such kind of recycling did take place there, it is unlikely that the resulting pattern of Sb-contamination would duplicate so closely the composition of the Balkan samples and those from the Western Mediterranean.

Admitting the speculative character of such reasoning, a probable technology of adding minor quantities of mosaic glass (estimated to less than 3 – 5% of the whole batch, based on a generalised Sb$_2$O$_3$ content of tesserae of around up to 2 wt%) in the primary glass-production furnaces of the 6$^{th}$ c. composition seems plausible. The addition of a certain amount of regular vessel cullet at this stage is also probable (hence, the overall volume of reused glass could be higher) since there are no technological reasons for preferential use of tesserae. However, this is impossible to be confirmed analytically since re-melting glass without colourants would not leave particular compositional signatures in the final melt.

Several important differences become apparent when the comparison of the 6$^{th}$ c. composition and the 5$^{th}$ c. Mn-decolourised composition is summarised. Firstly, a shift to glassmaking sands with higher concentrations of mineral impurities may indicate a change of the production location, but probably still within the same broader region (defining the geographical position of this region is beyond the limits of the present study$^\ast$). Furthermore, a modified recipe with an approximate doubling of added manganese compared to the earlier formula suggests a certain technological change. Possibly, the introduction of this new production formula is related to a switch to a new source of Mn-containing ingredient (denoting new supply routes?). At the same time, the primary production of 6$^{th}$ c. composition glass likely marks a transformation of the general modus operandi, analytically recognisable as the addition of pre-existing mosaic glass (and general cullet?) to the starting batch of sand and natron. Moreover, an expected increase of cullet recycling at the stage of secondary glass manufacture seems to have had a further impact on the 6$^{th}$ c. composition. Therefore, despite the geochemical resemblances to the 5$^{th}$ c. Mn-decolourised glass, the 6$^{th}$ c. makeup should be considered as a distinct primary group

$^\ast$ The discussion on this subject in Schibille et al. 2016 was published after the submission of the present thesis, and therefore it could not be fully taken into here.
and not as a geologically determined evolution of the earlier composition.

As already mentioned, the dataset from the Lower Danube allows for a definition of a sub-group within the 6th c. composition. It resulted most probably from internal shifts within the same primary production centre, and is labelled here as ‘iron-rich sub-group’ because of the extreme concentrations of Fe₂O₃, reaching ca 3.5 wt% (Table IV.1.) which is not correlated with TiO₂ (Fig. IV.7.). The sub-group is tentatively interpreted as a consequence of natural heterogeneity and gradual deterioration of the glass-making sand (Cholakova et al. 2015), and it features a slightly different trace oxide pattern as well (Fig. IV.9.). Nevertheless, shifts in production technology are also evident (indicated by slightly lower MnO and Sb₂O₃ levels – Fig. IV.8.; Fig. IV.12.B.), and this may imply certain adaptations to changes in available raw material resources. Interestingly, considerable number of samples of the same high-iron sub-composition is found in the Western Mediterranean, apparently excluding the possibility that this is a regional (recycling driven?) phenomenon established for the Lower Danube only (Fig. IV.7.). At the same time, this sub-group is absent in the Galeata assemblage, and is present with only five examples in total from the Cyprus sites and the Iustiniana Prima datasets (Fig. IV.8.B.). A likely explanation of this pattern may be related to changes over time in the 6th c. composition primary production. The Galeata glass is tentatively dated to the very beginning of the 6th c. and consists entirely of main group samples. In Dichin, dated up to ca AD 580, the iron-rich sub-group appears as a minor fraction within the 6th c. composition (five samples out of 19), while in Odartsi, presumably representing the end of the 6th – early 7th c., the proportion of both varieties is nearly 1:1 (20 high-iron samples out of 43). Therefore, a hypothetical date of ca mid-6th c. is plausible for the moment of emergence of the iron-rich sub-group. The gradual increase of its presence over time, relative to the main group, possibly indicates a gradual transfer of the production to more contaminated areas of the sand deposit, similarly to the internal compositional evolution of the 5th c. Mn-decolourised glass (see Section III.2.4.).

Overall, the interpretation of the sub-variations of both the 5th and the 6th c. primary glass groups as gradual developments of, and posterior to their respective initial makeups implies that compositional patterning may be a valid chronological
indicator as well (i.e. it is not exclusively provenance-oriented). The finds studied in the present research point to a characteristic correlation of the changes in vessel shapes and manufacturing techniques, and the emergence/disappearance of the chemical groups (Appendix A.2.). The gradual progression is seen in the 5th–6th c. glass vessels – a transition to a dominating pontil technique, reduction of additional decoration, and significant prevalence of lighting devices over tableware made of glass (first column of the table in Appendix A.2.). These processes at the level of secondary glass working in the Lower Danube mark a craft tradition continuity occurring over time, even though placing strict chronological internal boundaries would not be possible. At the same time, the distribution of samples within each archaeologically defined group according to their chemical composition (second to fifth columns of the table) confirms that a certain succession existed in the spread of the primary glass groups and sub-groups. This correlation does not imply a causal relationship between the alterations of the primary glass-making locations and/or recipes, and the transformations in secondary glass vessel manufacture. The table rather illustrates that the developments of these two parallel strands of the overall glass industry likely took place simultaneously. Such ‘two-sided’ positioning of the finds, i.e. both as vessel morpho-typology/manufacture/function, on the one hand, and as glass composition, on the other, allows for a detailed refinement of the relative chronology within a timespan of two centuries, hence providing a high-resolution reconstruction of the changes over time. According to this outline the iron-rich sub-group of the 6th c. composition is probably chronologically the last primary glass makeup of the early Byzantine period to reach the Lower Danube region.

A more general insight into the patterns presented in Appendix A.2. may also help to better understand the dynamic nature of the primary glassmaking in Late Antiquity. The seeming long-lasting co-existence of (competing?) constant glass groups should be rather regarded, in the case of 5th c. Mn-decolourised and 6th c. compositions, as continuous processes of emergence, evolution, and downturn of various production establishments, with their chronological shifts, overlaps and interrelationships. The speculations about the broader directions and meanings of these processes may not be conclusive at the present stage of research. Nevertheless,
the data from the Lower Danube region suggest that the 6th c. glass industry was likely characterised by resourceful and adaptive technological choices, undoubtedly embedded in particular historical and socio-economic settings. A certain degree of adjustment, overall functionality and less attention to the visual aspect seem to have had a leading role, resulting in a gradual cessation of some earlier traditions such as the effective glass decolourising or the aesthetics of eye-catching vessel decoration.

Finally, an attempt to situate the characteristics and the economic significance of the 6th c. composition within the broader primary glass industry of the 6th – 7th c. needs to take into account other contemporaneous major glass groups (e.g. Levantine I – Freestone et al. 2008b) which may have not reached the Lower Danube region at that time. Detailed comparisons between assemblages across the Mediterranean and beyond (cf. Freestone et al. 2008a, Table 4 and Ceglia et al. 2015, Table 4) would contribute to trace the wider areas of distribution of the different primary groups, and hence to a reconstruction of different interregional networks towards the end of Late Antiquity. Nevertheless, such a long-term objective would require a close understanding of the relevant site chronologies and historical contexts, which is outside the scope of the present study.

IV.2.3. Varia

The remaining seven samples from Odartsi are presented briefly as varia in the following paragraphs since they cannot be attributed to neither of the previous two major groups in the assemblage (i.e. the yellow to dark-olive HIMT beakers with cracked-off rims, and the 6th c. composition goblets and lamps of various colour tints).

Two fragments are consistent with the 5th c. Mn-decolourised composition commented upon earlier in the discussion on the Dichin glass (see Section III.2.4.). In Odartsi this group is represented only by a rim fragment decorated with blue trails and a stemmed goblet fragment (ODR 36, ODR 1 – Fig. IV.13., Appendix B.2.6). The first find matches neatly the range of manufacturing techniques used in the 5th c. vessel production in the Lower Danube region – thickened fire-rounded rim produced with
**Fig. IV.13.** Odartsi – *varia*: fragments of diverse vessels and a window pane piece belonging to different compositional groups. ODR 30 is a fragmented lower part of a cobalt-blue stemmed goblet with a thick layer of whitish surface corrosion. Note the horizontal scratches on the internal side of the vessel opening of ODR 35, and the contamination due to a minute metal (?) particle left in the folded inwards rim.
pontil and decorated with semi-marvered thin trails of blue glass. The reconstruction of the fragment suggests that this could be a drinking vessel with straight vertical walls, or possibly an oil lamp. A possible date at the end of the 5th – early 6th c. based on morpho-typological parallels (cf. Foy 1995, form 21b, c) is indirectly supported by the chemical makeup of ODR 36 identified as intermediate sub-group of the 5th c. Mn-decolourised composition. The same date (or more probably the early 6th c.) and compositional affiliation are valid for the stemmed goblet ODR 1. Both these fragments demonstrate slightly elevated values of certain recycling indicators (PbO, Sb₂O₃ – Appendix B.2.6). They could be hypothetically linked to the very last decennia of production and circulation of the intermediate sub-group of 5th c. Mn-decolourised glass at the very beginning of the 6th c. A certain deterioration of its quality and possibly local mixing with the then newly started 6th c. composition supplies have likely taken place (see Section III.2.4.). Such a reconstruction is in agreement with the site history of Odartsi since the settlement, unlike Dichin, had uninterrupted occupation during the transitional decennia between the two centuries (see Section IV.1.1.).

A flat window pane fragment ODR 42 (Fig. IV.13., Appendix B.2.8.) is comparable to the broader field of the 5th c. and 6th c. compositions but its precise identification is ambiguous, not at least because of a lack of LA-ICP-MS data. A plausible explanation of its ‘blurred’ makeup might be a higher degree of cullet re-use/recycling and mixing which might have caused an increase of potash and magnesia (ca 1.4 wt% K₂O and 1.6 wt% MgO) and a slight decrease of soda (ca 16 wt%). Alternatively, the find could be related to a still poorly understood small group of 6th c. glasses possibly produced using plant ash as flux (Drauschke and Greiff 2010, see Section V.2.7.; Appendix A.5.). Nevertheless, the relatively low concentrations of alumina and titania in ODR 42 (ca 2 wt% Al₂O₃ and 0.11 wt% TiO₂) strongly resemble the 5th c. Mn-decolourised composition. The preferred but still hypothetical interpretation, acknowledging the lack of trace oxide data, is that ODR 42 represents a working practice of repeated cullet recycling (over-recycling?) leading to inevitable contamination and mixing of different compositions which might be typical for the window pane manufacturers. This could be even more valid at the regional and local small-scale level of production where the use of inexpensive materials of lower quality
Table IV.2. Diagnostic oxides of the cobalt-blue samples from Odarsti and Serdica compared to the samples from Iustiniana Prima (data after Drausche and Greiff 2010, Tab. 1 – recalculated average values of three samples). The upper part of the table presents Isings 111 finds, the lower part unworked chunks. See Appendix B.2.8. for detailed data.

<table>
<thead>
<tr>
<th>sample</th>
<th>CoO</th>
<th>CuO</th>
<th>PbO</th>
<th>MnO</th>
<th>Sb₂O₃</th>
<th>Fe₂O₃</th>
<th>Al₂O₃</th>
<th>TiO₂</th>
<th>CaO</th>
</tr>
</thead>
<tbody>
<tr>
<td>ODR 11</td>
<td>295</td>
<td>1363</td>
<td>4241</td>
<td>1236</td>
<td>10</td>
<td>0.83</td>
<td>2.35</td>
<td>0.13</td>
<td>5.51</td>
</tr>
<tr>
<td>SER 23</td>
<td>342</td>
<td>1169</td>
<td>4014</td>
<td>1629</td>
<td>7</td>
<td>1.14</td>
<td>2.50</td>
<td>0.17</td>
<td>7.43</td>
</tr>
<tr>
<td>ODR 30</td>
<td>483</td>
<td>1579</td>
<td>2851</td>
<td>1534</td>
<td>250</td>
<td>1.24</td>
<td>2.84</td>
<td>0.14</td>
<td>6.85</td>
</tr>
<tr>
<td>SER 20</td>
<td>1132</td>
<td>1140</td>
<td>4739</td>
<td>3921</td>
<td>275</td>
<td>1.33</td>
<td>2.38</td>
<td>0.14</td>
<td>7.32</td>
</tr>
<tr>
<td>Iust Prima</td>
<td>400</td>
<td>1500</td>
<td>3760</td>
<td>760</td>
<td>430</td>
<td>1.04</td>
<td>2.33</td>
<td>0.13</td>
<td>5.31</td>
</tr>
</tbody>
</table>

is expected. Indirect support for such a hypothesis comes from the Price Edict of Diocletian which specifies the lowest prices for window panes, i.e. 6-8 denarii per pound, compared to 13-24 denarii per pound of raw glass and 20-30 denarii per pound of vessel glass (Whitehouse 2004).

A fragment of a jug/bottle handle ODR 51 made of colourless glass is the only example within the studied site assemblage which may well predate the 5th c. (Fig. IV.13., Appendix B.2.1.). The lower part of the handle is decorated with shallow vertical ribs resembling the manufacture of certain late Roman vessels (e.g. jugs Isings 120-127). However, a definite morpho-typological reconstruction is impossible for such a small fragment. The chemical makeup of ODR 51 supports an earlier date. It belongs to the Mn-decolourised variety of Syro-Palestinian primary glass compositions attested in the 4th c. Jalame assemblage (Brill 1988, Tabl. 9 – 3, 4; cf. Foy et al. 2003, Série 3.1.; see Section V.2.1.).

Two fragments of stemmed goblets Isings 111 from Odartsi deserve comments separately from the main group of this vessel type because of their peculiar intentionally coloured transparent dark-blue glass. Apart from the slightly smaller sizes, ODR 11 and ODR 30 do not differ morphologically from the rest of the goblets with plain stems in the studied assemblages. However, in terms of their chemical composition they represent a particular makeup of cobalt coloured glass (Fig. IV.13.; Appendix B.2.8.). This compositional variety does not seem too widespread, and only
two more similar samples from Serdica were analysed in the present project (a chunk SER 20 and a stemmed goblet SER 23, see Section V.2.7.). At the same time, evidence from published assemblages demonstrate that such dark-blue (Co-blue?) unworked chunks and Isings 111 fragments were found at numerous sites in the Balkans and the wider region. Three chunks from Iustiniana Prima closely resemble the finds from Odartsi and Serdica in their cobalt concentrations (400 ppm CoO – cf. Table IV.2.) and most probably related to them increased levels of CuO and PbO (Drauschke and Greiff 2010, 41 – samples 188, 189, 281). Similar unworked pieces of dark-blue glass come from a workshop in Thessaloniki (Antonaras 2014, Fig. 12.10). Dark-blue fragments from stemmed goblets are known from the same assemblages from Iustiniana Prima and Thessaloniki (Drauschke and Greiff 2010, Pl.1; Antonaras 2014, Fig. 12.17), from Bulgaria (Gomolka-Fuchs 1992, 264; Gomolka-Fuchs 1991, n1341), and the Black Sea region (Odessus – unpublished; Crimea – Golofast 2009, 316, Fig. 17). Remarkably, all the examples were found in 6th c./ late 6th – early 7th c. contexts. One of the goblets from Odartsi was found together with a coin dated to AD 570-571, i.e. it most probably belongs to the final decennia of the early Byzantine occupation of the site.

The production of intensely coloured cobalt-blue glass is a well-known technological practice long before the early Byzantine period. The analysed finds from the late 6th c. demonstrate a consistency of the approximate proportions of CoO, CuO, PbO, Fe$_2$O$_3$ (Table IV.2.) and certain trace oxides (As$_2$O$_3$, NiO – see Appendix B.2.8.) which tentatively suggests a common source of the cobalt colourant (cf. Gratuze 2013b, Table 5.1.4.; Silvestri et al. 2012, Fig. 6d). This resemblance could possibly indicate that the colouring may have taken place at the stage of primary glass making, thus the cobalt-blue composition would represent a separate primary production group. As an alternative, the addition of the colourant independently in various secondary workshops is also possible, similar to the production of black glass in small scale local workshops in the late antique Balkans (Rehren et al. 2012; Cholakova and Rehren 2014). However, this practice would have required steady supplies of the Co-bearing ingredient from a particular source.

The trace oxide pattern of the cobalt-blue samples from Odartsi and Serdica shows that they cluster relatively tightly, within the field of the main 6th c. composition
The values of titania also support such an expected geochemical affinity to this contemporaneous primary glass group (Table IV.2.). At the same time, the manganese contents of the cobalt-blue glasses are generally too low (accordingly, SrO levels are also lower), and two of the samples contain only negligible amounts of antimony oxide. These characteristics are not consistent with the reconstruction of the 6th c. glass recipe as suggested above (see Section IV.2.2.).

More analytical data is necessary to define the nature (and possible varieties?) of the 6th c. cobalt-blue glasses. They may represent a coloured version of the 6th c. primary glass group (e.g. some instances of mosaic glass – Silvestri et al. 2012, 2182) which might be obtained by adding the colourant to base glass of 6th c. composition in secondary workshops. Nevertheless, the four samples from the present dataset could possibly imply a specialised smaller scale primary glassmaking within the production area of the 6th c. composition (i.e. sharing the geochemical characteristics of the 6th c. composition) but following a different technology of additives. The second hypothesis would reinforce the suggested diversity of primary glassmaking factories within the broader region of the production of the 5th c. and 6th c. compositions, as implied by the existence of their respective sub-groups.

Finally, the last fragment from Odartsi to be briefly commented upon is ODR 35 – a neck sherd of a small bottle made of light bluish transparent glass (Fig. IV.13., Appendix B.2.8). It was most probably used as a container for small volumes of specific substances (liturgical, medical, or cosmetic), and the inner side of the opening bears scratches from a stopper or an instrument (needle or probe?) used to reach the content of the bottle. The morphological characteristics of the fragment (simple irregular folded inwards rim) are not too indicative of its date but its chemical composition suggests a quite intriguing interpretation. The sample is characterised by slightly elevated iron oxide value (ca 1 wt% Fe₂O₃), not too high soda (nearly 16 wt% Na₂O) and intermediate titania concentration (0.23 wt% TiO₂), which is uncommon in the present dataset. The trace oxide ratios of ODR 35 imply that this find is close to the geochemical markers of the broader Egyptian primary glass production (see Fig. III.9.B.), and close to the ‘HIMTb’ sub-group in particular. Nevertheless, the strontium
Fig. IV.14. Alumina and lime concentrations of ODR 35 situated against the HIMTa, HIMTb, and HIT samples from the present dataset and Egypt II samples (published data from Tel el-Ashmunein and Tel Aviv, after Bimson and Freestone 1987 and Freestone et al. 2015a).

Oxide value of ODR 35 is the lowest one analysed in the present study (ca 300 ppm SrO and 8.91 wt% CaO) and separates it from the HIMT composition (Appendix A.4.). Such low SrO concentrations are found in glasses produced from inland sand deposits, with lime inclusion deriving from mineral limestone instead of marine shells (Freestone 2006, 209). The most logical interpretation is to associate ODR 35 with Egypt II glass – a slightly later primary group of natron glass probably produced in Middle Egypt (Bimson and Freestone 1987; Gratuze and Barrandon 1990). A comparison of alumina and lime levels of ODR 35 and Egypt II samples from Tel el-Ashmunein in Egypt and a recently published assemblage from Israel confirms that such a compositional identification is plausible (Fig. IV.14.). Similar examples of Egypt II composition are known from Butrint in the Western Balkans (Schibille 2011) and a few sites from the Levant (e.g. Greiff and Keller 2014), but in general this group does not seem too widespread. ODR 35 differs from most of the published Egypt II finds with its manganese content (0.4 wt% MnO) which possibly is an intentional additive to counteract the mineral contaminations in the glassmaking sand.

The interpretation of ODR 35 as Egypt II glass composition commonly dated to the 8th – 9th c. is not consistent with the chronology of the early Byzantine occupation
of Odartsi which ended in the beginning of the 7th c. (ca AD 615). Instead of suggesting an earlier date for the beginning of Egypt II glass production (e.g. Schibille 2011, 2946) the present single case might be related to the early medieval settlement which emerged in the late 8th – early 9th c. in the ruins of the early Byzantine site at Odartsi. The vessel was most probably imported to the Lower Danube region as finished object and does not represent local secondary glass working of Egypt II primary glass.

The vessel glass assemblage from Odartsi confirms most of the main conclusions from the study of the Dichin glass while also allows for a more detailed insight into the 6th c. glass distribution in the Lower Danube region. The finds from Odartsi which predate the 6th – early 7th c. phase of the site are not too abundant, and consist mostly of a small set of HIMT fragments and only a few examples of 5th c. Mn-decolourised composition and certain other chemical groups. The overwhelming part of the assemblage is formed of stemmed goblets and oil lamps made of 6th c. composition which should be related to the final period of occupation of the settlement, as late as ca AD 615. The studied dataset from Odartsi provides evidence of an iron-rich sub-group within the 6th c. composition, and reinforces the conclusion that these supplies of primary glass dominated as almost the only glass group distributed in the Lower Danube region during the final decennia of Late Antiquity.

* Different glass compositions were used in the 8th – 9th c. local glass workshops in the region, according to the published data (Wedepohl 2007).
Chapter V is the final part of the discussion of the primary dataset in the thesis. It presents the finds from Serdica which, in contrast to the Dichin and Odartsi site assemblages, are selected deliberately in order to address particular aspects of the distribution and usage of glass vessels but not to outline a general picture of the late antique glassware from this town. Likewise Chapter III and Chapter IV, the first part the present of Chapter V provides background information about the history of Serdica and the archaeological sites within the town. The integrated classification of the studied finds consists of six main groups and several outliers. Most of the groups outlined here complement the data from Dichin and Odartsi while certain other groups shed light at the earlier glass distribution of the late 3rd – 4th c. and regarding direct evidence of secondary glass working in the Balkans.
V.1. Introduction

As an urban centre *par excellence*, Serdica (present-day Sofia) has an uninterrupted development for already nearly two millennia. Therefore, it differs considerably from Dichin and Odartsi in terms of its history, archaeological characteristics (not least, by the scale of accumulation and diversity of archaeological structures), and the overall significance. A thorough research on the late antique glass from Serdica is a long-term task far exceeding the limits of the current project. Instead, the present analysis of selected finds excavated predominantly at the ‘MS 8-II’ site in Serdica addresses particular questions arising from the research on the glass from Dichin and Odartsi. The leading objective of this approach is to achieve a more complete primary database for a reconstruction of the distribution networks at different levels in the Lower Danube region.

V.1.1. The site

Serdica is located in present-day Western Bulgaria, approximately in the centre of the Sofia valley, one of the Sub-Balkan valleys to the South from the Balkan Mountain Range (Fig. V.1.). This fertile agricultural area, also known for the abundance of thermal mineral springs was continuously populated since the Neolithic period. During the Iron Age, the Thracian (or possibly, Celtic) tribe of the Serdi supposedly established their political centre at the location of the subsequent Roman settlement. The earliest archaeologically attested traces of Roman occupation at the site are dated to the mid-1st c./ the third quarter of the 1st c. AD, and probably mark the presence of a Roman military unit (Ivanov in press). The actual urban development of Serdica started in the

---

* The following summary of the site development is based mostly on the publications by Ivanov (in press), Dinchev (2013; 2014), and Boyadjiev (2002), even though a vast range of literature exists on Serdica; its review is outside the remit of the current research.
Fig. V.1. The Roman and early Byzantine town Serdica: general location to the South of the Danube, and position of the fortified spaces in the original topography of the immediate area (after Dinchev 2013; http://blog.geographydirections.com/tag/map/ http://www.bg-zlato.com/images/BIG.jpg - accessed June 2015). In the lower map, note the location of the hill-top settlement near Samokov, to the South of Serdica (see Appendix A.8.).
very beginning of the 2nd c. when the administrative rank of *municipium* was granted to the settlement. The new town was named Ulpia Serdica after the emperor Trajan – *Marcus Ulpius Traianus* (98-117), and became one of the important civil centres of the Roman province of Thrace. The first stone-built ramparts were constructed ca AD 176-180, and surrounded an area of ca 18 ha (Serdica I – Fig. V.1.). Roman Serdica had a typical orthogonal inner planning, with large private buildings and numerous public edifices such as *bouleuterion*, *gerousia*, *praetorium*, theatre, several baths, sanctuaries, etc. (Fig. V.2.). In AD 251 the town most probably suffered one of the earliest raids of the Goths in the Balkans. The following reconstruction was reinforced by the imperial support of Aurelian (270-275) who in AD 271 declared Serdica a capital of the newly established province of Dacia Aureliana (from AD 285 transformed into Dacia Mediterranea, see Appendix A.1.). At that time, or in the beginning of the 4th c. a project for a larger fortified space to the North of the initial defences was partly implemented (Serdica II – Fig. V.1.), and the overall area of the town was increased to ca 84 ha. The prosperous urban development of Serdica during the late Roman times is attested by an improvement of the street network, construction of various rich private and public buildings, including a large amphitheatre, baths, Christian basilicas, decorated tombs, etc. In AD 343 the town hosted one of the ecumenical councils of key importance for the early Orthodox doctrine. In the mid-5th c. Serdica was damaged by the Huns invasions in the Balkans, even though there are no archaeologically attested traces of considerable destructions. By that time the fortified area was reduced back to the initial outline of the earlier walls. In the end of the 5th c. and during the reign of Justinian I (527-565) these ramparts were strengthened, and an external defensive line of *proteichismata* was constructed (Fig. V.2.). The archaeological data suggest a gradual decline of the urban characteristics of Serdica towards the end of the 6th c. The town most probably lost its significance by the early 7th c., even though it was not abandoned. Serdica continued its transformed existence into the medieval and post-medieval periods, gradually developing into the modern city of Sofia (Fig. V.3.).

---

* This prosperity was probably supported by the central imperial government, as suggested by the famous phrase attributed to Constantine I the Great (306-337) – 'Serdica – that is my Rome' (Vachkova 2013).
Fig. V.2. The Roman and early Byzantine town of Serdica: general plan with most of the excavated areas within the city walls and the approximate locations of the ‘MS 8-II’ site and the ‘VTB’ site (after Ivanov 2013).

Four particular sites in Serdica and its neighbouring sub-urban region provided materials for the current project. The ‘MS 8-II’ site is situated nearly in the centre of the ancient town (Fig. V.2.; V.4.A.). It was excavated from 2010 to 2012 in the framework of a major rescue project (Ivanov in press; Ivanov 2013). Almost all the Serdica glass finds studied here come from the late antique layers of this locality. Additional samples were found in similar urban contexts from the ‘VTB’ site excavated in 1977 in the area of the Western defensive walls (Fig. V.2.). Furthermore, a villa
The 'Obelya' site and a mausoleum at the 'Lozenets' site are both situated within the modern city, in close proximity of ancient Serdica (Fig. V.3.; V.4.B.). The sites are dated to the 4th – first half of the 5th c. (Stancheva 1981; Ivanov 2004), and they provided supplementary evidence of glass vessel usage in the wider settings of the late antique town.

V.1.2. The vessel glass assemblage and sampling

Almost the entire archaeological fieldwork in Serdica and its surroundings is conducted as rescue excavations necessitated by the ongoing reconstructions of present-day Sofia (Fig. V.3.). Accordingly, the amount and complexity of the accumulated field data and finds are immense, as expected for such kind of urban archaeology of a living city with nearly two thousand years of history. Therefore, acknowledging the limitations of the present project, this Chapter V is not aimed at developing a complete overview of the late antique glass from Serdica. Any thorough comparisons between the assemblages from Dichin and Odartsi on the one hand and the Serdica glass on the other hand are also avoided due to the impossibility to achieve a suitable dataset which would be fully representative of the whole late antique town.

Instead, a more feasible and pragmatic approach is preferred. Certain vessel fragments and production debris from Serdica were deliberately chosen for the present study*. After a refinement of this initial set a targeted sampling of 57 pieces was done. They were measured by LA-ICP-MS and EPMA within three analytical runs in total, with a significant prevalence of the LA-ICP-MS analyses (see Section II.2.1.2.; Table II.3.). The majority of the materials were found in 2010 and 2011 at the ‘MS 8-II’ site (52 samples)**, while the remaining five samples come from the earlier excavations at the ‘VTB’ site (two samples), ‘Lozenetz’ (two samples), and ‘Obelya’ (one sample). The main purpose of this selection is not to form a representative

---

* These glass finds from Serdica are part of the collection of the Sofia History Museum.
** This site yielded a huge amount of glass fragments (a total number exceeding hundreds), dated from the 1st c. AD to post-medieval times. Therefore, the studied set of 52 samples, unearthed predominantly during the first campaign of the excavations could give an idea about the range of the late antique glass from ‘MS 8-II’ but this selection is not suited for reliable quantifications of the groups.
Fig. V.3. Location of Serdica within the modern city of Sofia, and the positions of two suburban sites (Lozenets and Obelya) which provided samples for the current study (after Google Earth; accessed September 2015).
dataset of the entire Serdica glass but to address particular questions arising from the study of Dichin and Odartsi assemblages. In addition, certain samples were included in an attempt to complement the data regarding some underrepresented groups (e.g.}
Levantine I, antimony decolourised glass, high status vessels, cobalt-blue glass). Finally, the chance to examine glassblowing waste and unworked chunks from at least two production contexts at the ‘MS 8-II’ site significantly contributed to compensating for the virtual absence of such a category of finds in Dichin and Odartsi.
The studied finds from Serdica demonstrate a considerable diversity of glass colours and techniques of vessel finishing, as this is the intended effect of the selective approach and targeted sampling. The colour range includes natural light-blue and blue-green, clear decolourised or nearly colourless, dark-blue, dark-purple, and a variety of yellow-brown tints. The vessels are predominantly free-blown, with a single exception of optic-blowing (SER 39). The techniques of finishing and decoration represent different kinds of cold-working (cracked-off rims, polishing, wheel-engraving, facet and figure cutting, etc.), and hot-working (fire-rounded rims, applied trails and blobs).

The following sections present in summary the six main groups and some outliers in this purpose-built assemblage. The data from Dichin and Odartsi suggested that certain correlations may exist between the vessel shapes, manufacturing techniques, and/or decoration and the chemical composition. In order to test the validity of these working-stage conclusions, three visually identified groups from Serdica (yellow to dark-olive cups, vessels with blue-trailed decoration, and stemmed goblets Isings 111) were selectively sampled. Luxurious vessels with elaborate decoration form a separate and more extensively discussed group, while the remaining two groups consist mostly of unworked chunks and working waste.

**V.2.1. Unworked chunks/ a bowl – aqua-blue/ colourless glass (Levantine I composition)**

This group comprises unworked chunks from ‘MS 8-II’ which were brought together at the initial stage of visual assessment of the materials due to their clear aqua-blue glass tint which resembles the colour of the Levantine I vessels from Dichin (cf. Fig. V.5. and Fig. III.4.). In total ca 20 such small chunks, measuring not more than 2-3 cm were found at two different spots at the site, and six of them were analysed (Appendix
Fig. V.5. Serdica – raw glass chunks (probably 5th – 6th c. ?) and a bowl fragment with wheel-cut decoration (late 4th c.) made of Levantine I glass composition. Note the visual difference between the naturally coloured chunks with no additives and the Mn-decolourised vessel sherd.

B.2.1.). Additionally, a vessel fragment SER 24 was joined to this group after its chemical makeup was found to be comparable to the composition of the chunks (Appendix B.2.1.).

The unworked chunks were discovered in mixed contexts containing late antique and medieval material, and they can be broadly linked to the 5th – 6th c. period of the site but a narrower dating based on the stratigraphy is not possible. Some of the chunks have preserved adhering of whitish furnace lining. The initial assumption based on their colour was confirmed – they all belong to the Levantine I primary glass group with manganese in background trace concentrations reflecting the natural makeup of the glassmaking sand (Table V.1.). The trace oxide data demonstrates that these chunks cluster closely with the Levantine I samples from Dichin, even though they do not entirely overlap (Fig. V.6.A.). At the same time, most of the chunks (except SER 6) have higher soda and lower alumina and lime concentrations than the typical levels in
Table V.1. Average chemical composition of the unworked chunks of Levantine I composition from Serdica (n=5; all oxides in wt%; only P$_2$O$_5$ in ppm). Sample SER 6 has a slightly different makeup (its diagnostic oxide concentrations are highlighted separately) and is excluded from the averaged values. See Appendix B.2.1. for detailed data.

<table>
<thead>
<tr>
<th></th>
<th>SiO$_2$</th>
<th>Na$_2$O</th>
<th>Al$_2$O$_3$</th>
<th>CaO</th>
<th>K$_2$O</th>
<th>MgO</th>
<th>P$_2$O$_5$</th>
<th>Fe$_2$O$_3$</th>
<th>TiO$_2$</th>
<th>MnO</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>69.5</td>
<td>16.5</td>
<td>2.72</td>
<td>8.15</td>
<td>0.61</td>
<td>0.79</td>
<td>811</td>
<td>0.47</td>
<td>0.09</td>
<td>0.02</td>
</tr>
<tr>
<td></td>
<td>14.7</td>
<td>3.21</td>
<td>10.82</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Levantine I glass (e.g. Freestone 2006, Table 2). This compositional feature brings them closer to the group of the earlier Roman blue-green glasses (Fig, V.6.B.), implying a certain geochemical affinity between the latter and the Levantine I group, as already suggested elsewhere (e.g. Jackson and Paynter 2015, 26). On the other hand, the internal heterogeneity within the Levantine I composition itself is a well-known phenomenon (Rehren et al. 2010). However, more evidence is needed to better understand the nature of these variations and their possible chronological significance.

The Levantine I chunks found at ‘MS 8-II’ are quite small, not numerous, and at least some of them seem as deliberately rejected pieces due to the contaminating ceramic adhering. No finished objects made of the same composition were identified in the studied set from Serdica. Furthermore, the chunks contain only negligible trace concentrations of glass colourants (Appendix B.2.1.) which most probably come from the natural mineral impurities in the glassmaking sand and not from recycling of cullet contaminated with coloured pieces. The virtual absence of Sb$_2$O$_3$ supports such an assumption. The levels of potash and phosphorus are also lower compared to the finished vessels of Levantine I glass (Fig. V.7.B.), suggesting that the chunks have not been through multiple cycles of re-melting. Therefore, these finds likely represent residues of overseas supplies of original fresh Levantine I primary glass which were not enough abundant to be worked separately and therefore were probably ‘dissolved’ in the general mixed batches in the secondary workshops (see Section VI.1.1.2.).

The vessel fragment SER 24 is another example of Levantine I composition from Serdica, representing the manganese decolourised variety of this primary makeup. Its shape is comparable to Isings 106b type found in numerous late Roman contexts, even though the wider opening of the Serdica fragments suggests it cannot be
reconstructed as a beaker but rather as a bowl. The vessel is thick-walled, with cracked-off rim, a shallow groove just below it and traces of careful wheel-polishing on the rim edge and the upper part of the walls (Fig. V.5.). The cold-working techniques of finishing of SER 24 resemble the Levantine I vessels from Dichin (Fig. III.4.), and are mirrored by various late Roman finds from the 4th – 5th c. Balkans (e.g. Weinberg and Stern 2009, n306-308, Ružić 1994, type VII/12c) and farther afield (e.g. Harden et al. 1987, n46). Such linear wheel-polishing/ engraving is often combined with decoration.

![Graph showing trace oxide ratios](image)

**Fig. V.6.** Levantine I glass samples from Serdica and Dichin: the comparison of the trace oxide ratios confirms their geochemical resemblance (**A.**), while the alumina vs lime scatter-graph shows a spread of the Serdica chunks towards the field of the Roman glass (**B.**). Representative ‘Roman glass’ values from Foster and Jackson 2009 and Drauschke and Greiff 2010. The trace oxide pattern of SER 6 matches the main cluster while the same sample stands separately from the rest of the chunks in the Al₂O₃–CaO scatter-graph.
Fig. V.7. Levantine I glass samples from Serdica and Dichin: A. The deliberate addition of MnO in SER 24 has a decolourising effect, while the slight increase of MnO in the Dichin vessels is a result of contamination with recycled glass. Note the logarithmic scale of the MnO concentrations. B. A comparison of the potash and phosphorus concentrations found in unworked chunks and finished vessels.

of applied blobs of blue glass, and quite possibly the vessel from Serdica may have had a similar ornamentation. The fragment was found in a late 4th c. context, and such a date is in good agreement with the general chronology of this group. Most probably the find represents the import of high-quality finished vessels to the Balkans during the late Roman period, taking into account the general distribution pattern of this category of glassware.

Interestingly, similar vessel finishing is known from the secondary production
site at Jalame in Israel dated to the second half of the 4th c. (Davidson Weinberg 1988, 86). Furthermore, the Jalame assemblage provides also close parallels to the chemical composition of SER 24 (Brill 1988, Table 9-7). As mentioned earlier, the sample from Serdica belongs to the Levantine I group, indicated by its low soda level (15.7 wt%), increased alumina and lime, and the overall chemical makeup with low concentrations of sand impurities (Appendix B.2.1.; Fig. V.6.). The MnO content of 0.64 wt% is an intentional recipe element (Fig. V.7.A.), also found in the Jalame glass and the decolourised Levantine I glass from other regions of the Mediterranean and beyond (e.g. Foy et al. 2003, Série 3.1.; Gallo et al. 2014, AQ/2a; Foster and Jackson 2009, Levantine 1a).

V.2.2. Cups with cracked-off rims – yellow to dark-olive/ brown glass (HIMT composition)

The initial analyses of the yellow-olive fragments with cracked-off rims from Dichin and Odartsi demonstrated that they invariably belong to the HIMT primary glass group (Rehren and Cholakova 2010). Therefore, as a working hypothesis, a certain correlation was supposed between this particular chemical makeup and the craft style of cut and unworked or slightly smoothed rim edges and no use of pontil, generally typical for the 5th c. However, the aim to test this hypothesis based on the recently excavated materials from ‘MS 8-II’ could not be entirely implemented since the set of finds from this site available for study contained only a single fragment of this group (SER 46). Therefore, two additional finds from the ‘VTB’ (SER 29) and ‘Obelya’ (SER 30) sites were joined to the present database and a single fragment from the Samokov site as well (G 4; see Appendix A.8.). The analytical results showed that one more sample from ‘MS 8-II’ belongs to the HIMT composition (SER 35), even though it differs from the main group by its artefact characteristics.

Despite this adjusted targeted selection, the present group remained relatively small, containing five samples only (Fig. V.8., Appendix B.2.2.). This is a significantly lower number compared to the respective groups from the Dichin (16 samples) and Odartsi (10 samples), and a variety of reasons may have caused such a disproportion.
Therefore, at the present stage of research no interpretative conclusion should be based on these preliminary proportions.

Four of the vessels in the present group belong to Isings 96a/107 type – deep cups or bowls with outsplayed rims. There are no base fragments preserved but the cracked-off and unworked rims suggest that the pontil technique was not used in their manufacture. SER 29 and SER 30 are decorated with applied blue blobs arranged in patterns (Fig. V.8.), while SER 46 and G 4 are plain. The overall quality of vessel finishing is not too high, probably except for SER 29 which has thinner walls, with a light wheel-abraded line below the rim. The fragments from Serdica are broadly
contemporaneous with the Dichin and Odartsi assemblages, even though SER 29, SER 46, and G 4 were found in disturbed contexts with mixed late antique material (4th – 5th c.; 5th – 6th c.?) which cannot provide closely specified dating. SER 30 was found in the upper (and hence, chronologically most recent) layers of the ‘Obelya’ villa rustica site, which was devastated and abandoned in the mid-5th c. (Stancheva 1981). Accordingly, the first half of the 5th c. is a plausible date for this find, which also is in good agreement with the data from Dichin.

These finds belong to a distinct and quite popular group of late antique glassware commented upon in the discussion on the Dichin assemblage (see Section III.2.3.). The Serdica fragments demonstrate an intriguing absence of one of the main vessel type in this group – tall beaker Isings 106b-c, which is predominant in Dichin and Odartsi but could not be identified in the present sub-set. Perhaps this difference reflects certain intra-regional specifics of the vessel distribution but more data is necessary for their better understanding.

The assumption, based on the materials from Dichin and Odartsi, that the yellow-olive vessels with cracked-off rims were produced in the secondary glass workshops situated within the Lower Danube region finds further indirect support in the Serdica assemblage. The overall moderate level of quality of the Serdica fragments and the fact that this production has reached smaller sites (e.g. ‘Obelya’), or remote settlements (e.g. ‘Samokov’, see Appendix A.8.) suggests that it was affordable for a wider intra-regional consumption. It seems unlikely that imported goods would have been extensively distributed at this level of the inter-regional networks since, undoubtedly, this would be the ‘market niche’ of the regional vessel production centres active at this time. However, direct evidence of the origin of these vessels, such as substantial amounts of working debris still has to be identified in the Lower Danube.

Compositionally the vessels in the present group belong to the HIMT primary glass, confirming the initial hypothesis of a correlation between chemical glass group and vessel category (the main discussion of HIMT composition, including the Serdica finds, is in Section III.2.3.). The majority of the samples from Serdica represent the
‘HIMTb’ variety and only a single example (SER 46) has the more extreme ‘HIMTa’ composition (Appendix B.2.2.). However, this chemical differentiation does not correspond to a clear separation in terms of vessel morpho-typology, manufacturing style, or dating. Therefore, no interpretation of this grouping is suggested here, similarly to the Odartsi HIMT fragments (see Section IV.2.1.), not at least due to the small number of such finds from Serdica.

The oil lamp base SER 35 is the only example within the present sub-set which differs from the standard deep cup shape (Fig. V.8.). Typologically the lamp belongs to the group of suspended lighting devices with pointed bases (e.g. G 80, G 81; cf. Fig. V.17., SER 33, SER 34) but this vessel has much thicker lower part and an overall different craft style and glass composition. SER 35 is the only example of such a lamp made of HIMT yellow-olive glass and stands out as an unusual vessel in the analysed dataset from the Lower Danube. Nevertheless, such lamps with massive bases are known from the Mediterranean (e.g. Gallo et al. 2014, Fig. 3; Antonaras 2010b, Fig. 3d; Gliozzo et al. 2015a, PNE17, 18), also made of olive glass of HIMT composition. Taking into account the absence of similar vessels from the studied assemblages, it seems plausible that this is a particular case of import of a finished glass object produced outside the Eastern Balkans. The context of discovery of SER 35 is tentatively dated to the 6th c., i.e. it is chronologically later than the main group of the yellow-olive glasses. This may be an indication of a later occurrence of HIMT composition although other explanations are possible as well (prolonged use of the lamp, or secondary re-deposition of the fragment). Interestingly, the analyses of SER 35 demonstrated a higher degree of heterogeneity of the glass∗.

V.2.3. Cups with elaborate engraved/ cut decoration – colourless glass (Sb-decolourised composition)

Two vessels stand out in the present set from Serdica because of their remarkable decoration in the techniques of cold glass working. These two finds represent the

∗ An observation based on two measurements of a single sample; accordingly, this single sample is represented by two analyses – SER 35(1) and SER 35(2).
luxurious section of the late Roman glass vessel industry and both are made of antimony decolourised glass. They are discussed below in greater detail because of their higher significance within the overall studied set of materials. Additionally, one more fragment from the Serdica assemblage was joined to the present group because the analytical results demonstrated that it belongs to the Sb-decolourised chemical makeup.

A small hemispherical cup SER 28 comes from the ‘MS 8-II’ site. It is a thin-walled vessel manufactured and decorated entirely with cold glass working techniques: very skilful linear and figured wheel-cutting/ engraving, rim cutting and polishing, and possibly, occasional free-hand incisions (Fig. V.9.). The glass is colourless with a dense milky-white corrosion layer, very typical for some high antimony compositions. Most probably the figural composition was covering the entire vessel but only a minor fraction of the scene has survived: part of a human figure holding a burning torch (?), a very small part of another figure/ object on the opposite side of the torch, and small stars as additions in the space between the figures. This find belongs to the wide and rather diverse group of late Roman engraved vessels with figured decoration which is extensively discussed in the literature (e.g. Harden 1960; Fremersdorf 1967; Caron 1997). The research so far has established different styles, workshops and places of
### Table V.2. Average chemical composition of the antimony decolourised samples from the present dataset (mean based on samples SER 28, SER 52, and G 84; all oxides in wt%; only P$_2$O$_5$ in ppm). See Appendix B.2.4. for detailed data.

<table>
<thead>
<tr>
<th></th>
<th>SiO$_2$</th>
<th>Na$_2$O</th>
<th>Al$_2$O$_3$</th>
<th>CaO</th>
<th>K$_2$O</th>
<th>MgO</th>
<th>P$_2$O$_5$</th>
<th>Fe$_2$O$_3$</th>
<th>TiO$_2$</th>
<th>Sb$_2$O$_3$</th>
<th>MnO</th>
</tr>
</thead>
<tbody>
<tr>
<td>wt%</td>
<td>69.8</td>
<td>18.2</td>
<td>1.86</td>
<td>5.95</td>
<td>0.33</td>
<td>0.39</td>
<td>428</td>
<td>0.34</td>
<td>0.07</td>
<td>0.42</td>
<td>0.01</td>
</tr>
</tbody>
</table>

manufacture, and a remarkable variety of pagan, Christian, or secular iconographies on these vessels. It is hard to identify an exact parallel of the vessel shape of SER 28 although engraved deep hemispherical bowls with wheel-cut groove(s) just under the rim are well-known (Caron 1997, N6, N9, both dated to the 4$^{th}$ and late 4$^{th}$ – early 5$^{th}$ c.). A closer definition of the decoration style is not possible because some important details such as the outline of the human face and eyes are missing. Nevertheless, the lack of wheel-abraded details may be indicative. The small stars around the figure are very similar to those found on a fourth century bowl from Italy (Paolucci 1997, 150-151). The Serdica cup is not exceptional in the context of the late Roman glass repertoire from the Lower Danube region, where several other examples of engraved figured vessels are already known (e.g. Milčeva 1999). Even if these luxurious pieces do not necessarily represent the work of the most central and ‘high-class’ late Roman ateliers, they certainly are imported and should not be regarded as mass-production or local Eastern Balkan manufacture. SER 28 may originate from a workshop in Northern Italy (cf. Paolucci 1997) and its presence at the ‘MS 8-II’ site is most probably a result of the specific mechanisms of distribution of the high-status goods.

The fragments of SER 28 were found in a stratigraphic context dated to the late 4$^{th}$ or early 5$^{th}$ c., and based on the style of the engraved decoration of the vessel itself, it could be broadly attributed to the second half of the 4$^{th}$ c.

The cup is made of glass decolourised with a relatively high amount of antimony and contains only traces of manganese (5800 ppm Sb$_2$O$_3$; 140 ppm MnO; Appendix B.2.4). A deliberate selection of glass-making sand of high purity is evident from the low levels of alumina, lime and the minor oxides (Table V.2.; Fig. V.12.A.). At the same time, the low concentrations of metal oxides linked to glass colouring do not indicate extensive and indiscriminate recycling (Appendix B.2.4.). This would imply an
attentive choice of the craftsmen to maintain the highly valued colourless appearance of the glass, possibly through a preferential use of fresh primary glass, as opposed to cullet raw material which could contaminate the melt.

Two more samples from the studied dataset belong to the same compositional group of Sb-decolourised glass produced with low-impurity sands. A single find from Dichin was already commented upon (G 84, see Section III.2.6.; Appendix B.2.4.), while the other sample (SER 52) comes from the ‘MS 8-II’ site in Serdica. This base sherd is concave and plain, produced without a pontil rod (Fig. V.9.), resembling the manufacturing technique of some of the HIMT vessels (cf. Fig. III.8. – G 16). It was found in a late 4th – 5th c. context but most probably the fragment itself is not later than the early 5th c. Unfortunately, no fragments of the upper part of this vessel (probably a beaker) were found, and hence, it is impossible to determine its exact shape and whether it had a decoration or not.

The use of antimony oxide as a decolouriser gradually ceased by the end of the 4th c. AD being replaced by manganese, according to the widely accepted understanding (Sayre 1963). Such a chronological pattern is indirectly reaffirmed by the current dataset from Late Antiquity, where only three samples (out of nearly 200 in total) are Sb-decolourised, with MnO content of less than 200 ppm. Nevertheless, throughout the 4th century the distribution and most likely the primary production of colourless glass made of low-impurity sand using antimony oxide are clearly attested as well. The composition of SER 28 is comparable to the results obtained on late Roman materials from Britain (Foster and Jackson 2010), some cage-cups (Sayre 1963; Brill et al. 1999-2012), and other examples of luxurious late antique glass (Meek 2013). Such evidence points to a prolonged (but probably not too abundant) existence of this specific primary glass group which seems to be particularly related to the finer vessel manufacture of the late 3rd – 4th c. (Jackson and Foster 2014). However, evaluating the character of its possible links to the earlier Roman colourless glass (e.g. Paynter 2006; Schibille et al. 2012b), the slightly later group of manganese decolourised glass produced with similar low-impurity sands (see Section III.2.4.), or to the circulation of

---

* Two more samples with high Sb-content (the cage-cup samples SER 26 and SER 27) are discussed separately below due to the peculiarities of their composition.
various antimony decolourised glasses in Roman and late Roman Egypt (Rosenow and Rehren 2014) needs further analytical work. Based on the data from SER 28 and corresponding G 84 and SER 52, the spread of this compositional group in the Lower Danube region in Late Antiquity is now confirmed and the nature of its distribution can be tentatively associated with the movement of the ‘wants, not needs’ (Mundell Mango 2009a, 6), i.e. luxurious elitist items.

The last vessel in the present group is an exceptional figured cage-cup made of colourless base glass of the main body (SER 26) and of cobalt-blue glass of the openwork decoration (SER 27). The vessel was found in a highly fragmented state with numerous pieces missing∗, in a mausoleum located in the vicinity of ancient Serdica (‘Lozenets’ site – see Section V.1.1., details and full publication in Ivanov 2004). The vessel was deliberately included in the studied set of samples in an attempt to complement the category of luxurious late antique glassware which is underrepresented in Dichin and Odartsi. Moreover, such an addition is in good agreement with the overall characteristics of the main site assemblage from Serdica, i.e. the ‘MS 8-II’ set of finds. A recent discovery of another cage-cup fragment∗∗ at ‘MS 8-II’ (Fig. V.11.C.; full publication in Ivanov 2013) demonstrates that the distribution of these late Roman high-status vessels was not restricted to grave complexes only, and covered the urban settings of Serdica as well. Therefore, the analysed figured cage-cup (SER 26 and SER 27) is more than just a chance or rare inclusion in a particular funeral context – this find reflects a regular pattern of the glass vessel distribution in the studied region. Chronologically this phenomenon seems to predate the majority of the groups discussed so far since the two diatreta from Serdica are dated to the second half of the 4th c. according to their contexts of discovery.

The decoration of the analysed cage-cup combines both figured and geometric patterns (Fig. V.10.; V.11.A-B.), similarly to the vessel in the Cathedral Treasury of San Marco, Venice (Volbach 1971, n13; Meredith 2015, n50). The figured composition represents motives of the Dionysiac imagery very close to a fragment from the

∗ This is due to an evident robbing of the mausoleum during antiquity (Ivanov 2004).

∗∗ The second fragment is not analysed since it was discovered when the current project sampling was already completed and no additions to the sample export documentation were possible.
Fig. V.10. Serdica – fragmented figured cage-cup made of antimony decolourised (SER 26) and cobalt-blue glass (SER 27), second half of the 4\textsuperscript{th} c. Graphical reconstruction after Ivanov 2004 (left); working stage of the vessel restoration with the individual fragments mounted on a plastic support which affects the visual appearance of the colourless glass (photo courtesy G. Mavrov – Sofia History Museum).

Metropolitan Museum of Arts (Smith 1949; Meredith 2015, n91) and broadly comparable with the famous Lycurgus cup (Harden and Toynbee 1959; a recent literature review in Elsner 2013). Interestingly, despite this resemblance in iconography both quoted analogies are made of dichroic glass while the Serdica cage-cup shows a more conventional combination of colourless and cobalt blue glass. However, figured cage-cups decorated with glass of the same cobalt blue tint are also known (Weinberg and Stern 2009).

It is beyond the scope of the present discussion to continue further on the archaeological aspect of the late Roman cage-cups which are subject of numerous studies (e.g. an overview in Weinberg and Stern 2009; on the technique of production: Lierke 2013; on the distribution: Meredith 2009; on another vessel from Bulgaria:
Fig. V.11. Serdica: A. The cage-cup from the ‘Lozenets’ site – reconstruction of the figural scene of cobalt-blue glass (after Ivanov 2004); B. Details of the fragments; C. Cage-cup wall fragment from the ‘MS 8-II’ site, second half of the 4th c. (not analysed; drawing and graphical reconstruction after Ivanov 2013).
Shepherd 1999; a recent general overview: Meredith 2015). It suffices to point out that both recently found diatreta from Serdica add to the growing number of such finds in the Balkans∗ which indicates a very active process of their distribution. Accordingly, the popularity of these high status vessels during the 4th c. marks the existence of a particular class of prosperous and socially significant persons within the region as a relevant consumer milieu of the openwork glassware.

The interpretation of the chemical composition of the cage-cup found at the ‘Lozenets’ site (samples SER 26 and SER 27 Appendix B.2.4.) merits closer attention since the analytical research on the late Roman diatreta is not too extensive, except for the continuous interest in dichroic glass (most recently in Freestone et al. 2007). The figured cage-cup from Serdica provided an opportunity for scientific compositional analysis of both the colourless and blue glasses. Only five similar data pairs are known from the literature (Brill et al. 1999-2012). However, no substantial enquiries have explored so far how instructive such kind of analytical data could be in respect to the organisation of this highly complex and specialised glass vessel manufacture.

The present discussion is an attempt to interpret both compositions of the cage-cup not separately but as an intentionally formed ‘technological assemblage’. It is believed that the diatreta manufacture, presumably divided into two stages, i.e. first shaping (most probably by blowing) the blank and then producing/ finishing the open-work decoration, would have required particular knowledge, selection and control of the materials used, and operational skills at each of the two stages. Therefore, the following paragraphs are focused on two main questions: (1) Are there two different base glass compositions, or was the same starting material used for the main body and the openwork decoration of the cage-cup; (2) What is the nature of the added colorant. The possible answers to these questions are then linked to the implications regarding the working practices of the diatreta producers and the raw material procurement for this highly specialised manufacture which, in turn, would inform regarding its general mode of organisation.

∗ The total number of well documented finds from the Balkans is twelve (eleven listed in Meredith 2015 and another one in Ivanov 2013).
Several works emphasize that the base glass of cage-cups is characterized by antimony decolourising and purer raw materials, as already mentioned regarding SER 28, and even linking the ‘exceptional artistic merit’ of *diatreta* to ‘superior decolouration through the use of antimony’ (Sayre 1963; 280; Foster and Jackson 2010; Brill *et al.* 1999-2012, vol. 3). The glass of SER 26 is Sb-decolourised, with nearly 6000 ppm Sb$_2$O$_3$, but the level of manganese (ca 1600 ppm MnO) is much higher than the supposed background concentrations as seen for example in SER 28 (Table V.3.; Fig. V.13.B.). Of the available cage-cup analyses from the literature, only the one from the Benaki Collection has similarly elevated manganese oxide in its colourless part (Brill *et al.* 1999-2012). Thus, the cage-cup from Serdica may represent an occasional or fairly pragmatic choice of the glass workers to include a certain amount of cullet, including Mn-decolourised pieces in the melt without affecting the colourless appearance of the glass. There is not enough evidence to hypothesize unavailability of fresh glass as a reason for glassworkers to entirely turn to cullet recycling. It seems more reasonable to assume that the glass-blowers who shaped blanks for such a special high-status items would have had regular access to the necessary raw materials, at the same time being flexible in their choices and not bound to a kind of exclusive supplies.

The blue sample of the figured cage-cup from Serdica – SER 27 – is cobalt coloured, containing 380 ppm CoO (Table V.3.). The colourant introduces additional amounts of NiO, CuO, probably Fe$_2$O$_3$, and possibly MnO and PbO (Appendix B.2.4.), a combination that has also been seen elsewhere (Gratuze 2013b; Paynter and Kearns 2011; Silvestri *et al.* 2012). The excess of antimony oxide in SER 27 composition is

<table>
<thead>
<tr>
<th></th>
<th>SiO$_2$</th>
<th>Na$_2$O</th>
<th>Al$_2$O$_3$</th>
<th>CaO</th>
<th>K$_2$O</th>
<th>MgO</th>
<th>MnO</th>
<th>Fe$_2$O$_3$</th>
<th>TiO$_2$</th>
<th>Sb$_2$O$_3$</th>
<th>CoO</th>
</tr>
</thead>
<tbody>
<tr>
<td>SER 26</td>
<td>66.9</td>
<td>20.2</td>
<td>2.23</td>
<td>6.70</td>
<td>0.31</td>
<td>0.77</td>
<td>0.16</td>
<td>0.64</td>
<td>0.11</td>
<td>0.6</td>
<td>4</td>
</tr>
<tr>
<td>SER 27</td>
<td>66.0</td>
<td>19.3</td>
<td>2.33</td>
<td>6.72</td>
<td>0.52</td>
<td>0.62</td>
<td>0.27</td>
<td>1.04</td>
<td>0.09</td>
<td>1.3</td>
<td>380</td>
</tr>
<tr>
<td>Co-blue layer</td>
<td>68.3</td>
<td>16.6</td>
<td>2.37</td>
<td>7.22</td>
<td>0.66</td>
<td>0.67</td>
<td>0.29</td>
<td>1.00</td>
<td>0.07</td>
<td>1.5</td>
<td>---</td>
</tr>
</tbody>
</table>

*Table V.3.* Chemical composition of the cage-cup from Serdica (‘Lozenets’ site) – the first row presents the colourless glass of SER 26, and the second row – the Co-blue glass of SER 27 (all oxides in wt%; only CoO in ppm). See Appendix B.2.4. for detailed data. The last row presents the composition of the Co-blue layer of a *patera* fragment from the Corning Museum of Glass (data after Brill *et al.* 1999-2012, vol. 2, 144-145; CoO concentration is not reported there).
puzzling (ca 1.3 wt% Sb$_2$O$_3$). However, such a high concentration is also found in the Co-blue layer of an openwork *patera* fragment in the Corning Museum of Glass (CMG) dated to the 4th c. (Fig. V.13.B.; Whitehouse 1997-2003, vol. 1, n480; Brill *et al.* 1999-2012, n3803, n3804), which seems to be the closest parallel of the coloured glass SER 27 (Table V.3).

The samples SER 26 and SER 27 are juxtaposed with the published data of similar sets of colourless body and coloured open-work glasses from five individual cage-cups in an attempt to address the question about a possible link between these two paired compositions. A scatter-graph of alumina and lime includes pairs of results for six blue decorated cage-cups and a few colourless only *diatreta* of the same Sb-decolourised composition (Fig. V.12.A.). Remarkably, all the cage-cup base glass samples line up very tightly with their respective coloured compositions, while differing from each other. Although the samples were randomly selected there is no random distribution which should be expected if each pair is formed by two independently produced and compositionally different glasses. Instead, all the pairs exhibit the identical pattern of elevated alumina in the coloured glass, by about 0.1wt% Al$_2$O$_3$, regardless of the type of the colorant (cobalt or copper). This may have resulted from the process of colouring itself if it took long enough to allow not only the necessary good homogenising but also a reaction between the melt and the ceramic material of crucibles used (Peake and Freestone 2014). Alternatively, it could indicate that a small additional amount of alumina is introduced with the colorant. A similar clear grouping of the pairs is seen when magnesia and titania are compared (Fig. V.13.A.), even though here the Serdica cage-cup and the CMG *patera* both demonstrate a much bigger spread in MgO values between colourless and cobalt blue composition than the other pairs. Even bigger differences within most of the pairs are observed in soda and potash concentrations, but still with a constant trend of increased K$_2$O and lower Na$_2$O in all coloured samples (Fig. V.12.B.). This again could be explained with certain side effects beyond the intentional control of the craftsmen during a prolonged glass melting/ colouring/ homogenising, such as potash vapour contamination from the fuel and probably evaporation loss of soda (Paynter 2008; Tal *et al.* 2008).
These consistent cage-cup data pairs strongly suggest that for each *diatretum* only one starting base glass was used both for the main body and for the open-work decoration. The same has been observed in other groups of late Roman luxurious vessels made of multi-layered glass, and linked to an easier and unproblematic annealing of the objects due to the use of near-identical compositions (Meek 2013). In the case of *diatreta* blanks this is even more important since any imperfections at the initial stage of their forming (specifically, higher internal stress even after annealing) could cause serious damage during the following glass-engraving/cutting process. Therefore, a positive answer is quite possible to the first question regarding the Serdica vessel, i.e. whether SER 26 and SER 27 represent the same base glass, and the same could be valid also for other polychrome cage-cups. This seems (at least from the available data) to have been an established and deliberate technological practice rooted in skills and empirical knowledge of working properties of the glass melt which the *diatreta* producers certainly had.

An obvious implication of this statement is that if the glassworkers were not supplied separately with colourless and coloured glass but used only one base glass, then the colouring for the external layer of the *diatreta* blanks happened immediately before their shaping (using separately procured colourants?), and was made in the same workshops and probably done by the same craftsmen, even though no conclusive proof for this hypothesis can be given. However, this assumption would mean that defining the base colourless composition allows further discussion regarding the second question, i.e. what is the nature of the added colorant and is it possible to explore the technology of glass colouring for *vasa diatreta*.

The Roman and late antique techniques for glass colouring are studied mostly on the basis of indirect compositional or microstructural evidence from mosaic tesserae and related materials (e.g. Paynter and Kearns 2011; Silvestri *et al.* 2012), combined with an experimental approach (Lahlil *et al.* 2010), or based on direct information obtained from production waste (e.g. Rehren *et al.* 2012; Cholakova and Rehren 2014). The existence of specialised glass colouring workshops which operated to supply mosaicist (with cakes to be cut into tesserae) and probably the *diatreta* manufacturers (with glass to be re-melted and blown) has been suggested (Freestone
Fig. V.12. Analytical data of *diatretra* and two other engraved vessels made of Sb-decolourised glass (a bowl fragment from Canterbury and SER 28). The pairs of colourless and coloured glass for each cage-cup indicated – open symbols: colourless; dark blue symbols: Co-blue; light blue symbols: Cu-blue (data from Brill et al. 1999-2012, Foster and Jackson 2010).
Fig. V.13. Analytical data of diatretra and two other engraved vessels made of Sb-decolourised glass (a bowl fragment from Canterbury and SER 28). Pairs of colourless and coloured glass for cage-cups indicated – open symbols: colourless; dark blue symbols: Co-blue; light blue symbols: Cu-blue. The outlined cluster in (B.) marks the late Roman diatretra with lower antimony oxide levels compared to the early Roman examples from Begram and Nijmegen (data from Brill et al. 1999-2012, Foster and Jackson 2010).
et al. 2007). However, the present results tentatively point to a somewhat different mode of organisation in respect to the cage-cup production, even though the technological links to the tesserae colouring should not be doubted.

Assuming that SER 26 represents the original starting composition and SER 27 is the final product of the glass colouring, an attempt is made to reconstruct the makeup and nature of the added colorant through certain mathematical modelling (Fig. V.14.; V.15.). The main reasoning here is that the quantity of the added material and the degree of concentration of the colouring substance in it should be negatively correlated, even though the actual values of both parameters remain unknown. In other words, if only a small amount of material is added, it should contain highly concentrated colorant and vice versa. A recipe consisting of a bigger quantity of base glass, i.e. SER 26 composition, and less amount of concentrated colouring additive would keep the compositional similarity between both layers of the blank as high as possible. An opposite approach would be a recipe of equal amounts of base glass and of less saturated colorant which would lead to a significant dilution of the starting makeup but probably easier homogenising of the final coloured melt. In addition, it should be stressed again that certain oxides could be affected by contamination during the colouring stage, and their values therefore do not necessarily reflect only the mixing of the original ingredients. The margins of analytical errors have to be considered as well筝.

Such a schematic modelling is not aimed simply at estimating the recipe, i.e. the ratio between the base glass and the colorant, if a definite answer here is possible at all. The discussion of SER 26 and SER 27 suggested so far that the colouring of the decoration layer of the cage-cup blank could have been done using the same glass as for the main body, most likely in the glass-working ateliers, immediately before blowing the vessel. Understanding the nature of the added colouring material would provide further insight into the technological choices of the craftsmen who operated at this level of elite production.

The concentration of cobalt is taken as the basis for the modelling of mixing

筝 The detailed calculations of the hypothetical colourant compositions are presented in Appendix A.6.
both starting materials (i.e. the colourless glass SER 26 and the hypothetical colorant), following the approach presented in Freestone and Gorin-Rosen 1999. Knowing that the base glass SER 26 contains virtually no cobalt and the product of colouring, i.e. the blue glass SER 27 has 380 ppm CoO, the hypothetical colorant should include about 760 ppm CoO if both materials are mixed in a 1:1 ratio, or about 1130 ppm CoO if the ratio is 2:1, etc. At the same time, comparing the major, minor and certain trace oxide levels in SER 26 and SER 27 allows to reconstruct their concentrations in the hypothetical colorant, proportionally to the variation of its cobalt content (Fig. V.14.; V.15.). Considerably elevated Sb\(_2\)O\(_3\), Fe\(_2\)O\(_3\), PbO, etc. need to have been present in the colorant to result in their elevated concentrations in SER 27. However, two minor oxides are present in lower concentrations in the blue glass compared to the base glass (MgO and TiO\(_2\)) which can only be explained by a dilution effect, i.e. in order to interpret the observed compositional pattern, the added colorant must have had lower levels of these oxides than the base glass. If the 1:1 recipe probably indicates the lower limit of the CoO range in the hypothetical colorant, the decrease of MgO concentrations from SER 26 to SER 27 defines its upper limit at approx. 1900 ppm CoO (Fig. V.14.). Any composition calculated with higher cobalt content/ lower proportion of colorant in the recipe would need MgO values lower than 0 wt% in order to sufficiently reduce the total magnesia content during the mixing operation (Appendix A.6.), which is obviously impossible. The same can be seen in the titania levels, indicating a similar maximum cobalt content on the colorant. Realistically, a lower limit for the maximum CoO content has to be assumed in order to maintain a reasonable minimum MgO content in the colourant.

Therefore, based on the present modelling and the data available so far, it is hard to support the hypothesis of a strongly concentrated ingredient added in small amount (i.e. a recipe ratio 9:1 – Appendix A.6.). It would be quite fascinating to speculatively identify a kind of strongly coloured pre-made glassy material (Paynter and Kearns 2011) which the diatreta-producers added to the base glass melt similarly to the use of Venetian ‘corpo’ and ‘anime’ a millennium later (Moretti and Hreglich 2009). Such a technological practice would have certain advantages – easiness of dosage of the colorant according to the needed tint and at the same time keeping the
Fig. V.14. Modelling of the mixing of the colourless glass SER 26 and the hypothetical colorant aimed at a reconstruction of possible ranges of the oxides in the colorant and the glass mixing ratios used (minor oxides). The stated compositional ranges are for 1:1 and 2:1 base glass to colorant respectively.
Fig. V.15. Modelling of the mixing of the colourless glass SER 26 and the hypothetical colorant aimed at a reconstruction of possible ranges of the oxides in the colorant and the glass mixing ratios used (major oxides). Certain oxides could be affected by side-processes during glass colouring (e.g. fuel ash contamination or evaporation loss), hence their hypothetical ranges are not necessarily representative of the original composition of the colorant.
entire cage-cup blank compositionally homogeneous. However, the comparison of SER 26 and SER 27 glasses demonstrates that such a technological reconstruction is very unlikely, ruling out as well the probability of re-use of small amounts of strongly coloured material such as tesserae containing 0.3-0.4 wt% CoO as reported in Paynter and Kearns (2011), or Bayley and Doonan (1999).

Instead, another scenario looks more plausible, i.e. mixing the colourless base glass with material of a lower colorant concentration in a recipe range of 1:1 to 2:1. Here, it appears that the hypothetical added substance is clearly a glass, containing approximately 760-1130 ppm CoO, and most of the major and minor oxides being in line with typical Roman glass composition (Fig. V.14; V.15.). The reconstructed concentration of 2 wt% or more $\text{Sb}_2\text{O}_3$ would successfully opacify that glass, as frequently seen in Roman tesserae production (Lahlil et al. 2010). In fact, the hypothetical composition of the added colorant has numerous similarities with the broader range of cobalt blue opaque mosaic glass (Paynter and Kearns 2011). This may indicate that the re-use of pre-existing tesserae/ cakes was part of the working practices of diatreta producers which would then disprove a possible special raw material supply for these high-status craftsmen. Instead, a rather widespread and long-standing tradition of acquiring and re-melting coloured tesserae (an example that chronologically postdates the cage-cups in Schibille and Freestone 2013) would seem to be pragmatically adopted by the producers of luxurious late Roman vessels. This re-melting would eliminate the initial antimony opacifying effect in the re-used mosaic glass, but would keep the elevated $\text{Sb}_2\text{O}_3$ concentration seen in SER 27 and the CMG patera.

The interpretation of the composition of the added material as mosaic glass implies certain inferences regarding the technology, decisions and organisation of diatreta manufacturers. As pointed out earlier, the supposed technological link between tesserae colouring and diatreta production cannot be doubted (Freestone et al. 2007). However, the parallels between glass used in mosaics and the hypothetical composition of glass used for colouring a diatreta blank cannot be seen as a ‘recycling’ process, that is relying mainly on non-regular procurement of secondary materials instead of a proper primary source of purposely produced supplies. A technology of
indiscriminate recycling may be valid in some cases of ordinary and lower quality vessel manufacture, probably within a generally stagnant economic environment (see Section VI.3.2.2.). In contrast, it is assumed that cage-cups differ from this model since they belong to a much higher technical and social level within the overall glass industry of the late Roman period. Supplying workshops which produced cage-cup blanks with glass deliberately coloured in concentrations suitable for and aimed at further mixing and diluting with the colourless base material is a plausible working practice, clearly contrasting in terms of its organisation with the straight secondary re-use of mosaic tesserae, or any kind of direct relationships (i.e. sharing/ exchanging coloured raw glass) between mosaicists and diatreta glass ateliers.

An attempt to apply similar modelling to the published data pairs of other cage-cups shows comparable results for the colorant possibly used for the blue glass of the CMG patēra (Appendix A.6.). Unfortunately, the calculations are less conclusive regarding the remaining pairs of diatreta listed in Fig. V.12.A., mostly due to the limits of the available analytical data (commented upon in Brill et al. 1999-2012: vol. 3, 391-392).

The discussion of SER 26 and SER 27 glasses provides an unexpected insight to the cage-cup production, and certainly more analytical data is needed to better understand the various aspects of late Roman luxurious glass manufacture. Nevertheless, the suggested interpretation strongly indicates that diatreta vessels represent not a chance combination of unrelated glass compositions. Instead, the technology proposed here involves the use of only one base colourless glass: unaltered in the main body, and coloured with added material in the decoration layer. This approach allows reconstructing a process of intentional, skilful and knowledgeable manipulation of different raw materials which fits well such a specialised and elite production. The added colorant resembles mosaic glass compositions, posing the question about supply chains and choices of diatreta producers. Such an inquiry illustrates the likely distinction between high-status and ordinary glass vessel production, going beyond the conventional descriptive approach and at the same time opening new directions for diatreta research.
V.2.4. Vessels with blue trail decoration – colourless glass (5th c. Mn-decolourised composition = Série 3.2.)

The analytical work on the assemblages from Dichin and Odartsi revealed a certain consistent link between the blue trail decorations on vessel rims on the one hand, and on the other hand, the chemical composition of the base colourless glass used for the production of these vessels (see Sections III.2.4. and IV.2.3.). All the studied samples from Dichin and Odartsi belonging to this category of particular ornamental style were identified as 5th c. Mn-decolourised composition. This indicates that the secondary workshops which followed the craft tradition of blue trailed vessel finishing likely shared the same supplies of raw glass. The fragments found at the ‘MS 8-II’ site in Serdica provided an opportunity to test this initial hypothesis. During the first excavation campaign at ‘MS 8-II’ eight fragments of rims and bases decorated with marvered, semi-marvered, or standing in relief trails of dark- or light-blue glass were found, and seven of them were analysed. The compositional data confirmed that the entire group is produced of the same Mn-decolourised glass which prevails in the 5th c. contexts of Dichin and is identical with Série 3.2. from the Western Mediterranean (Foy et al. 2003). Additionally, four samples of unworked chunks and three samples of vessels with different morpho-typological and ornamental features found at ‘MS 8-II’ were joined to the blue-trail decorated set of fragment since they belong to the same 5th c. Mn-decolourised composition. Thus, the present group of this composition from Serdica consists of 14 samples in total (Fig. V.16.; Appendix B.2.6.).

The diversity of vessel shapes and decorations within the group of 5th c. Mn-decolourised glasses found in Dichin is partly confirmed in the present group from Serdica, despite the limitations of the targeted sampling approach. Although it is not possible to reconstruct full vessel profiles, bowls with fire-rounded and thickened rims are recognised (Fig. V.16., SER 56, SER 50 – cf. Cruz 2014, Fig. 7.2.3-4); vessels with narrow openings and vertical walls could be identified as beakers or lamps (Fig. V.16., SER 49, SER 51 – cf. Cruz 2014, Fig. 7.2.1.; Foy 1995, Forme 21b, c), and cups/beakers with applied ring bases are present as well (SER 54, SER 55, SER 57). Interestingly, the base fragments have no traces of pontil, while the blue trail decoration of the rims is likely produced using pontil technique. Likewise the similar fragments from Dichin
Fig. V.16. Serdica – fragments of vessels with blue trail decoration made of 5th c. Mn-decolourised glass, three fragments with different morpho-typology, and unworked chunks of same composition, late 4th – early 6th c. Note the poorer decolourising effect of MnO in some of the chunks (SER 2) which indicates that they may be pieces discarded after remelting. The variations of the blue glass colours suggest the use of different kinds of colouring additives for the decoration (the lighter-blue decoration of SER 57 and SER 31 resembles the tints of Cu-blue colourant, while most of the fragments seem produced with Co-blue ingredient).
(Cholakova 2009b, Tabl. VII), the Serdica examples have thicker trails covering the rim edges, while thinner spiral trails are carefully marvered flush into the vessel walls (e.g. SER 51 – a detailed picture in Fig. V.16.). A closer inspection of the fragments from ‘MS 8-II’ shows that regardless of their general similarity they are not identical, and do not denote a single production event or one-off procurement. Most probably this style of coloured ornamental effects represents a wider craft tradition of the 5th c., typical for the secondary workshops in the region. The majority of these fragments are dated to the late 4th – 5th c., according to their contexts of discovery and the overall stratigraphy of the ‘MS 8-II’ site. This date suggests that they possibly belong to the earlier phase of production and distribution of the 5th c. Mn-decolourised glass, as confirmed also by their low alumina levels (Appendix B.2.6.; see Section III.2.4.; Fig. III.14.).

Two of the unworked chunks in the present group have similar dates (SER 9: second – third quarter of the 4th c., SER 10: late 4th – early 5th c.) and reinforce available evidence of a possible pre-5th c. emergence of this primary glass group. Two samples (SER 31 and SER 55) differ from the main group in their compositional characteristics (e.g. Fig. V.16. – samples outliers), while SER 31 has also different decoration (a wheel- engraved groove and applied blue blobs), resembling the craft style of the contemporaneous HIMT vessel manufacture (see Section III.2.3.). Finally, two stemmed goblets Isings 111 (SER 41 and SER 42) and a chunk (SER 3) belong to the probably later intermediate sub-group of the 5th c. Mn-decolourised composition, with overall elevated concentrations of minor oxides and slight traces of recycling (see Section III.2.4.; Appendix B.2.6.). The goblet fragment SER 42 was found in a 6th c. context suggesting that the group likely had an internal compositional shift over time which went along with the transition to the 6th c. vessel repertoire in the secondary workshops.

To sum up, the analyses of the present group from Serdica confirm the conclusions based on the Dichin assemblage that the Mn-decolourised composition probably formed the main raw glass supplies to the Eastern Balkans during the 5th c. Vessels with blue trail decoration seem as a distinct and well-established production of the region. The Serdica finds also complement the data regarding the timespan of
circulation of the Mn-decolourised group, probably exceeding the strict chronological limits of the 5th c. – with a start in the late 4th c. and continuation into the very early 6th c.

V.2.5. Stemmed goblets and oil lamps – various glass tints (6th c. composition = Série 2.1.)

The set of the fragments in this group was formed as a result of the targeted sampling approach to the Serdica glass assemblage, similarly to the previous group of blue trail decorated vessels. The initial observation that the 6th c. phase at Dichin is characterised by a single glass composition and a quite restricted range of vessel morphology (Rehren and Cholakova 2014) was reinforced by the results obtained from the Odartsi finds (see Section IV.2.2.). The fragments from the ‘MS 8-II’ site in Serdica, mostly found in well-dated contexts provided an opportunity to further explore the nature of this relation between chronology, vessel type and chemical makeup.

All clearly recognisable pieces of stemmed goblets from ‘MS 8-II’ available for study after the end of the first field campaign were sampled (13 fragments in total). However, four of them belong to different compositional groups, and hence are discussed separately (see Sections V.2.4. and V.2.7.). Additionally, three oil lamp bases from ‘MS 8-II’ were joined to the set of stemmed goblets because their morpho-typological traits suggest that they fit the regional vessel repertoire of the 5th – 6th c. (cf. Fig. III.13., G 80 and Fig. IV.5., ODR 37, ODR 40). Lastly, four chunks of unworked glass were also identified as 6th c. composition. Hence, the overall number of fragments in the present group is 16 (Fig. V.17.; Appendix B.2.7.).

The finds from Serdica confirmed the conclusion based on the respective 6th c. glasses from Dichin and Odartsi that the colour tint range of the group varies significantly – from nearly colourless/ light-yellowish to blue-greenish and yellow-brown, probably as an effect of the variable iron oxide and manganese concentrations (Fig. IV.8.) and different redox conditions. Therefore, the glass hue cannot be seen as

* In total 17 analytical results since a chunk of unworked glass is represented by two separate results due to the relatively higher degree of heterogeneity of this piece – samples SER 22(1) and SER 22(2).
a reliable criterion for a tentative recognition of the 6th c. glass makeup, as opposed to some other primary glass groups (e.g. HIMT glass). On the other hand, the vessel morphology seems as a more constant feature of the group – the overwhelming majority of the samples identified as 6th c. glass composition from the Lower Danube region belong to the stemmed goblet type Isings 111 (their overall number forms nearly 30% of the entire dataset of the present project). The goblet fragments from
Serdica match the general characteristics of the Isings 111 type discussed in detail based on the Odartsi assemblage (see Section IV.2.2.). All the examples belong to the variety made from a single gather of glass, with plain stem, or with a small knop. One of the fragments is optic blown (SER 39). However, the majority of the stemmed goblets are relatively poorly shaped, with some examples of obvious manufacturing flaws (Fig. V.17., SER 40) suggesting that they likely represent mass production of the local secondary workshops. The 6th c. date is confirmed by the context of discovery of the majority of the fragments in the present group, including the unworked chunks found in a well-dated assemblage of glass working debris (cf. Fig. VI.7., SER 21, SER 22).

As supposed at the initial stage of sample selection, the present sub-set from Serdica belongs to the 6th c. composition, with a quarter of them identified as part of its iron-rich sub-group (a detailed discussion of the 6th c. composition is given in Section IV.2.2.). At the same time, an important aspect of the assumed correlation between the chemical glass group and the Isings 111 vessel type becomes apparent from this site assemblage. Fourteen fragments of stemmed goblets from Serdica were analysed in total but five of them, i.e. more than one third, do not belong to the 6th c. glass composition. Accordingly, it is implausible to hypothesise a certain particular choice made by the producers of this vessel type or to affirm their deliberate preference of the 6th c. chemical makeup to some other compositions. Moreover, in other regions of the Empire the Isings 111 goblets which are morphologically similar to and contemporaneous with the Lower Danube finds were manufactured of different primary glass groups (e.g. Levantine I glass in Southern Jordan – Greiff and Keller 2014, Fig.17.3.4.; Fig. 17.2.). Therefore, the seeming interrelationship between the 6th c. glass composition and the stemmed goblet type most likely resulted from the coincidence/ the chance combination of the predominant primary glass composition supplied to the Lower Danube region during the end of Late Antiquity and the overall popularity of the Isings 111 vessels. The examples of stemmed goblets made of 5th c. Mn-decolourised glass from Odartsi and Serdica (see Sections IV.2.3. and V.2.4.) may illustrate the introduction of this vessel type in the repertoire of the workshops in the region in a certain moment before the definite domination of the 6th c. composition

\* Thirteen of them found at the ‘MS 8-II’ site and one at the ‘VTB’ site.
supplies. On the other hand, the cobalt-blue examples of Isings 111 and those made of glass likely produced with plant-ash (see Section V.2.7.) are contemporaneous with the main group of goblets made of the 6\textsuperscript{th} c. glass; they possibly represent small-scale or occasional import of ready vessels produced in workshops outside the Lower Danube region which had different networks of raw material procurement.

V.2.6. Tank furnace production debris (mixed Sb- and Mn-decolourised composition)

The fieldwork at the ‘MS 8-II’ site brought to light new direct evidence of the secondary glass working in Serdica. Remains of a small rectangular reverberatory tank furnace were found approximately in the centre of the excavated area, partly overlapped and destroyed by the construction of a later building (Fig. V.18.A-C.). The furnace was built of mudbricks with clay bonding and additional lining of finer clay. The bigger part of the tank bottom was found in situ, with parts of the destroyed walls collapsed on it. The detailed discussion of the furnace construction is beyond the objectives of the present research. No traces of preserved workshop walls, additional production features, or remains of any kind of other craft activities were found nearby, except three glassblowing waste pieces (Fig. VI.3.A.). The furnace is tentatively dated to the second half of the 3\textsuperscript{rd} – early 4\textsuperscript{th} c. (?) based on the stratigraphy and considering that the building above its remains belongs to the 4\textsuperscript{th} c. phase of the site. Numerous small chunks of glass detached from the furnace walls or left behind from the cleaning of the tank were collected, and four of them were analysed\textsuperscript{*} (Fig. V.18; Appendix B.2.5). Interestingly, the chunks represent a diversity of colours – from clear colourless to green. The selection of the four sampled chunks (SER 14-17) covers this range of tints, even though only relatively small compositional variations were found between the samples. This overall slight heterogeneity could be a result of the variable degree of furnace lining contamination, mixing of chunks from different batches, or poor homogenising of a single melt.

\textsuperscript{*} The group is represented by six analyses in total since two of the samples demonstrated a higher degree of heterogeneity and were considered as four individual results – SER 15(1), SER 15(2), SER 17(1), SER 17(2).
The glass from the Serdica furnace belongs to the antimony decolourised composition, with an average of nearly 0.6 wt% Sb$_2$O$_3$ (Table V.4.). However, this glass differs from the Sb-decolourised samples discussed earlier (see Section V.2.3.) because of its higher lime and alumina concentrations, and the presence of manganese in concentrations of ca 0.15 wt% MnO which exceed the expected natural background levels. The MnO content in glass above the expected threshold of mineral impurities in the glassmaking sands but lower than ca 0.5 wt% is commonly seen as a result of recycling of mixed batches, since such trace concentrations have no decolourising effect (e.g. Jackson 2005). Accordingly, the chunks from the Serdica furnace most probably represent a mixed batch consisting predominantly of Sb-decolourised

![Image of glass chunks](image)
Table V.4. Average chemical composition of the unworked chunks found in the tank furnace at the ‘MS 8-II’ site in Serdica (n=6; all oxides in wt%; only P₂O₅ in ppm). Sample SER 16 with increased alumina content is excluded from the averaging presented here (cf. Fig. V.19.). See Appendix B.2.5. for detailed data.

composition and adulterated with a certain amount of manganese containing glass. It is not possible to define whether this is a mixture of two parts of different fresh glasses, or combination of (various kinds of) fresh glass and cullet. The composition of the moil fragment found immediately next to the furnace differs from the chunks by its Sb₂O₃ – MnO ratio with a significant prevalence of MnO, and also by its higher alumina and lime values (SER 18; Fig. VI.3.A.; Appendix B.2.5.). It is compositionally very close to the Roman blue-green glass composition with added manganese although the antimony oxide content (0.17 wt% Sb₂O₃) indicates that this glass has had its own recycling history. Since the moil cannot be debris left behind from the blowing of the glass in the furnace, it strongly suggests that re-melting of pre-collected cullet was part of the working practices of the craftsmen operating the furnace.

Fig. V.19. Mixed Sb- and Mn-decolourised composition samples from the present dataset: the correlations illustrate joint recycling of glasses with higher alumina and lime concentrations (Mn-containing) and glasses with lower alumina and lime concentrations (Sb-containing). The sample outlier with elevated alumina can be interpreted as contaminated glass due to the contact with the clay furnace lining.

<table>
<thead>
<tr>
<th>SiO₂</th>
<th>Na₂O</th>
<th>Al₂O₃</th>
<th>CaO</th>
<th>K₂O</th>
<th>MgO</th>
<th>P₂O₅</th>
<th>Fe₂O₃</th>
<th>TiO₂</th>
<th>Sb₂O₃</th>
<th>MnO</th>
</tr>
</thead>
<tbody>
<tr>
<td>69.6</td>
<td>17.9</td>
<td>2.18</td>
<td>6.15</td>
<td>0.60</td>
<td>0.58</td>
<td>736</td>
<td>0.64</td>
<td>0.12</td>
<td>0.58</td>
<td>0.15</td>
</tr>
</tbody>
</table>

alumina enrichment from furnace lining contamination?
One more unworked chunk from ‘MS 8-II’ and a chunk found in a tank furnace from Philipoppolis demonstrate a similar combination of both decolourising additives (SER 8 and PLD 1; see Appendix A.8.; Appendix B.2.5.), as well as the already mentioned base fragment from Dichin (G 67, see Section III.2.6.). The chunk from Philipoppolis is the only securely contextualised example in this group, apart from the ‘MS 8-II’ furnace assemblage, and it is dated to the second half of the 3rd – 4th c. (Cherneva 2014). These samples (the chunk from Philipoppolis, ‘MS 8-II’ finds, and the fragment from Dichin) likely represent the earliest materials in the studied dataset, taking into account combined evidence of compositional results and the general chronology of the site contexts. They are linked to different primary glass groups of the Roman period (e.g. Freestone et al. 2015b) but brought together in the present discussion because of evidence of compositional mixing. Similar mixed glasses are well-known from other regions of the Empire (e.g. Jackson 2005; Silvestri et al. 2008.; Schibille et al. 2012b).

Joint re-melting of Sb-decolourised and Mn-decolourised Roman glass compositions is analytically recognisable by ‘lines of mixing’ between the fields of the two end-member glass types (Freestone 2015, 32-33; Jackson and Paynter 2015). The samples in the present group confirm that mixed recycling of Sb-decolourised glass with low alumina and lime levels and Mn-decolourised glass with higher alumina and lime levels results in certain correlations with positive and negative directions (Fig. V.19.). Remarkably, no vessel glass samples from Serdica that match these compositional patterns were identified in the present dataset, although this could be explained with the selective approach to this assemblage.

**V.2.7. Varia**

The remaining six samples from the Serdica set cannot be assigned to any of the previous groups and are therefore briefly discussed in the present Section as *varia*.

Two samples represent the cobalt-blue composition in circulation at the end of Late Antiquity in the Balkans. These are a small unworked chunk found at the ‘MS 8-II’
site in the context of glass working debris accumulation from the 6th c. (Fig. VI.7.B.), and a stemmed goblet Isings 111 fragment from the ‘VTB’ site also found in a 6th c. context (SER 20, SER 23; Fig. V.29.; Appendix B.2.8.). The fragments were deliberately selected for analysis in order to complement the data from the Odartsi assemblage where two more cobalt-blue stemmed goblets were found. The general discussion of this small but quite distinct group was presented earlier (see Section IV.2.3.). The unworked chunk from ‘MS 8-II’ could either indicate that the cobalt-blue glass was supplied as fresh raw material to the region, or that it was coloured in the local secondary workshops. Similarly, the question about the origin of the cobalt-blue stemmed goblets cannot be definitely answered at the present stage of research. They may well have been made in the Balkan workshops, or produced outside the region and imported as finished vessels. The present dataset tentatively implies a greater probability of the latter interpretation because of the overall finer manufacture of the cobalt-blue examples compared to the mass-produced Isings 111 vessels of the 6th c. glass composition. However, more evidence is necessary to address this problem.

A few chunks of glass with uneven dark-purple colour were found in the same accumulation of working waste from the 6th c. context at ‘MS 8-II’ (Fig. VI.7.B., V.20.). Their flat shape and the preserved adhering clay suggest that these pieces are debris left behind from secondary glass melting (molten glass spilled and solidified on a clay surface?) rather than chunks of fresh primary glass. One of the chunks (SER 19; Appendix B.2.7.) was analysed in order to understand whether this is a case of a particular glass colouring recipe. The chemical makeup of SER 19 generally matches the 6th c. composition (cf. Table IV.1.), with alumina and lime close to the higher end of the concentration ranges (3.09 wt% Al₂O₃; 8.73 wt% CaO) and the expected high SrO value (ca 840 ppm). Interestingly, the manganese level is not too high (1.28 wt% MnO), not exceeding the average for the main cluster of the 6th c. composition samples (i.e. 1.37 wt% MnO – cf. Table IV.1.). The purple colour of SER 19 is a result of the MnO additive but apparently the reason for this hue is not its abundant quantity but its particular oxidation state (namely, the presence of Mn³⁺). Accordingly, no convincing evidence is found to hypothesise a certain glass colouring recipe or technology since the redox conditions of the melt could be affected by a variety of factors, including
accidental and unintentional changes. The most plausible explanation of the dark-purple chunks from ‘MS 8-II’ is that they are waste pieces left behind from the re-melting of the 6th c. composition glass in one of the secondary glass workshops in Serdica.

A light-olive wall fragment (SER 25) found in uncertain context at the ‘MS 8-II’ site differs from the majority of the Serdica glass by its decoration consisting of big cut ovals (Fig. V.20.; Appendix B.2.7.). Although similar deep cups or beakers (named

![Fig. V.20. Serdica – varia: fragments of unworked glass and diverse vessels belonging to different compositional groups. The dark-purple chunk presented here was found together with SER 19 and SER 20 in the same assemblage of glass working debris, and is visually identical with the analysed purple piece SER 19. Note the uneven colour and the flat shape of this piece.](image-url)
‘Kowalk’ beakers) are occasionally known from the region to the South of the Lower Danube, their main area of distribution is outside the Empire, in the Barbaricum zones of Eastern Europe and Scandinavia (Gavritukhin 2011, Gomolka-Fuchs 1999; Whitehouse 1997-2003, vol. 3, n444). They are generally dated to the 4th or early 5th c. The discovery of such a vessel in Serdica is untypical but not unexpected since the margins of the Empire were not only spaces of frontlines but also regions of exchange and contacts. The discussion of the origin of these vessels requires special attention and opens entirely different perspectives of research, which exceeds the present project’s scope. However, the analytical results of this fragment provide an important insight ‘from the North’ towards the general development of the primary glass groups. Surprisingly, sample SER 25 matches very closely the 6th c. composition both in terms of major and minor oxide levels, and in trace oxide pattern (Table V.5.; Fig. V.21.; cf. Table IV.1.). Nevertheless, the morphological and manufacturing characteristics of the vessel definitely exclude the likelihood of such a late date for this find. Not many ‘Kowalk’ beakers are analysed so far but the available data of a 4th c. fragment from South Sweden (Stjernquist 2004a) reinforce the conclusion of a general similarity to the chronologically later 6th c. composition attested in the Balkans and the Mediterranean (Table V.5.). Thus, the chemical makeup of ‘Kowalk’ beakers implies a very intricate chronological pattern of different primary glass centres, and an even more complex picture of the distribution networks which supplied their production to various regions of the Empire and beyond. Any definite conclusion would be implausible at the present stage of research but the existence of an earlier phase of activity within the same area, occupied approximately two centuries later by the glass centre producing the 6th c. composition, is hypothetically possible.

<table>
<thead>
<tr>
<th>SiO₂</th>
<th>Na₂O</th>
<th>Al₂O₃</th>
<th>CaO</th>
<th>K₂O</th>
<th>MgO</th>
<th>P₂O₅</th>
<th>Fe₂O₃</th>
<th>TiO₂</th>
<th>MnO</th>
</tr>
</thead>
<tbody>
<tr>
<td>65.3</td>
<td>18.9</td>
<td>2.47</td>
<td>7.06</td>
<td>0.58</td>
<td>1.00</td>
<td>1161</td>
<td>1.76</td>
<td>0.18</td>
<td>1.32</td>
</tr>
<tr>
<td>67.8</td>
<td>17.0</td>
<td>2.40</td>
<td>7.90</td>
<td>0.58</td>
<td>0.90</td>
<td>---</td>
<td>1.00</td>
<td>---</td>
<td>1.20</td>
</tr>
</tbody>
</table>

Table V.5. Chemical composition of SER 25 (first row) compared to the composition of a ‘Kowalk’ beaker from Uppåkra, South Sweden (second row; data after Stjernquist 2004b; all oxides in wt%; only P₂O₅ in ppm). See Appendix B.2.7. for detailed data.
Finally, two more stemmed goblet fragments from ‘MS 8-II’ deserve brief comments because of their peculiar chemical makeup. As mentioned earlier, all the Isings 111 goblets available from this site were analysed following the initial hypothesis that they would belong to the 6th c. composition. However, SER 44 and SER 45 demonstrate a somewhat different affinity. Furthermore, a close inspection of their shapes reveals that they are also smaller, with finer manufacturing style compared to the mass of the goblets made of the 6th c. glass composition, and have a lighter blue-greenish colour (Fig. V.20.). SER 44 was found in a context broadly dated to the 5th – 6th c., while the context of discovery of SER 45 is assigned to the late 4th – 5th c., but it is possible that the fragment represents an intrusion into the earlier layers.

The composition of SER 44 and SER 45 demonstrates unusually elevated concentrations of potash, magnesia and phosphorus, the highest analysed in the present dataset (Table V.6.; Appendix A.5.; Appendix B.2.8.). Similar samples of unworked chunks are known from the 6th c. assemblage from Iustiniana Prima and are interpreted as evidence of the shift in the source of the soda flux used in glass melting – i.e. from mineral natron to ashes of halophytic plants (Drauschke and Greiff 2010). Nevertheless, more complex explanations are also possible since the concentrations of potash and magnesia in these samples are indeed elevated in comparison to the standard natron based glass compositions of Late Antiquity, but not reaching the levels commonly seen in the later plant ash glasses (cf. Freestone 2002, Fig. 4; Rosenow and Rehren 2014, Fig. 7; Cagno et al. 2012). A hypothetical chance contamination from fuel ash and vapour in the furnace is not excluded but it would possibly result in a more
random distribution of the K$_2$O, MgO and P$_2$O$_5$ values. Mixing of different flux ingredients in the primary batch, joint re-melting of different types of glass (i.e. natron and plant ash based), or adding ashes to pre-existing glass may also be supposed as working practices (cf. Freestone et al. 2008a; Bugoi et al. 2013) but the current set of only four samples is not enough representative for definite answers.

Nevertheless, the samples from Serdica and Iustiniana Prima have certain other common compositional traits, such as relatively low alumina, manganese in concentrations typically associated with glass recycling, a narrow range of titania, etc. (Table V.6.). These resemblances suggest that the glasses with higher potash and magnesia could possibly represent a particular primary production group which is closely linked to the 6$^{th}$ c. composition, likewise the cobalt-blue samples (see Section IV.2.3.). The trace oxide pattern supports such a general affiliation – interestingly, all
the samples outliers from Serdica seem to match the characteristics of the 6th c. composition (Fig. V.21.). This evidence confirms the major significance of the production region of the 6th c. glasses for the supplies to the Balkans. On the other hand, the observed diversity of compositions (i.e. 6th c. composition, Co-blue, high K- and Mg-composition) could imply a certain diversity of glass making traditions within that same common broader production area, further illustrating the complex dynamics of the primary glassmaking.

The studied glass finds from Serdica provide an opportunity to refine the inferences regarding the chronology, specifics of vessel manufacture and chemical makeup of certain groups which are identified in Dichin and Odartsi assemblages (e.g. Levantine I glass, 5th c. Mn-decolourised composition, HIMT glass, and 6th c. composition). As expected for a vessel glass collection from developed urban settings (as opposed to the semi-urban character of Dichin and Odartsi), a few examples of luxurious production (e.g. Sb-decolourised engraved and cut glass) are also found and studied in detail. Furthermore, the chance to explore production debris from Serdica extends the available information regarding the networks with regional significance of the late Roman period, which are dominated apparently by mixed Sb–Mn decolourised composition.
The Sixth Chapter of the thesis presents an interpretative synthesis of the primary archaeological and analytical data discussed in detail in the previous Chapters III, IV and V. There, an integrated classification of the glass groups was outlined for each of the studied site assemblages, and their general overview is the essential next step of the research. However, the following sections of Chapter VI are not intended for straightforward descriptive summarising. They are rather aimed at establishing a broader understanding about the significance of the glass groups; their meaning within the context of the economic chains and networks of distribution, and also—consumers’ preferences. The spatial differentiation of inter-regional, regional, and local networks (see Section I.1.) is used as a leading structuring principle of Chapter VI, while questions regarding the socio-economic mechanisms which underlie the distribution and questions of chronological changes are addressed as well.
VI.1. Inter-regional level of distribution networks

The inter-regional exchange or distribution of goods is commonly defined as movement between two different regions, not only geographically distinct but also having different material culture characteristics. Adjacent or not, these regions are considered as areas with an approximate radius of 100 – 300 km (Morrisson 2012a). Such a general spatial delineation is certainly useful, but at the same time it depends on particular characteristics of the studied territories and phenomena. In the case of the Lower Danube region, based on archaeological evidence of vessel glass, it is not possible (at least at the present stage of research) to clearly distinguish between the areas to the South and to the North of the Balkan Mountain range (Appendix A.1.). Moreover, during Late Antiquity these areas formed a continuum in terms of their socio-cultural and political development (see Section I.2.1.). Therefore, the Lower Danube region is considered part of the broader Eastern Balkans. Within the overall glass industry of the Empire, it was a region which hardly exported any kind of production, and was positioned entirely as a place of destination/endpoint of the inter-regional networks. In order to avoid potential ambiguities, the inter-regional distribution is seen here mostly as long-distance imports which probably reached the Eastern Balkans mainly through maritime transport from far afield.

VI.1.1. Inter-regional distribution of raw glass

The present sub-section discusses evidence of unworked raw glass which in the studied set of materials comes entirely from the urban contexts (production and dwelling) of Serdica and Philippopolis. As pointed out earlier, the overall division of the glass industry during the Roman and late antique periods implies that, as most regions of the Empire, the Lower Danube was quite distant from the primary glass production centres in the Eastern Mediterranean, and therefore relied on inter-regional distribution networks for its raw glass supplies. Accordingly, the finds of fresh raw glass
chunks in the Eastern Balkans are by definition indicative of the long-distance type of distribution; however, similar fragments could originate from secondary working.

**VI.1.1.1. Imported fresh raw glass and unworked debris of re-melting in secondary workshops: issues of differentiation**

Distinguishing between raw chunks produced on a large-scale in primary glass melting furnaces and broken pieces left behind from smaller secondary workshops is important since such a differentiation bears certain interpretative meanings.

From a theoretical point of view, the archaeological record should not be seen as a direct image of past realities but as a reflection and (an eventual) result of various practices, cultural and natural processes which include not only active use of materials but also refuse disposal (Schiffer 1972). Undoubtedly, a mass import and circulation of late antique fresh raw glass existed in the Lower Danube region. However, not every find of unworked chunks must be *a priori* associated with primary melting furnaces and seen as retaining the original chemical makeup of the raw glass produced there and traded to further afield. On the contrary, it is anticipated that the vast majority of such imported fresh material has been re-melted and used in the secondary production, leaving very little direct traces in the archaeological record in regions such as the Lower Danube. Provided that it was not affected by unexpected events, technologically rational management of these imported resources implies that only

![Image](image_url)

**Fig. VI.1. Unworked chunks of glass: A. Dichin, possibly primary Levantine I composition associated with the 5th c. site contexts; the adhering whitish furnace lining is well visible (not analysed, published in Cholakova 2009b, N116; cf. Fig. V.5.); B. Serdica, ‘MS 8-II’ site – samples SER 15 and SER 16 of mixed Sb-decolourised composition with traces of manganese from a secondary production tank furnace, late 3rd – 4th c. context (?)**.
chunks not suitable for re-melting (e.g. chunks with remnants of furnace lining adhering – Fig. VI.1.A.), should be intentionally discarded. Thus, it is not surprising that mostly such kind of pieces become visible in the archaeological record. Most probably, this is the reason for the overall paucity of finds of fresh raw glass chunks in the studied region. At the same time, unworked chunks from the secondary tank furnaces in Serdica (SER 14-17) and Philippopolis (PLD 1) represent a different type of material. The observations on their morphology alone would not allow for an accurate discrimination between fresh imported primary glass and chunks left from the filling of secondary furnaces based only on the morphology of the finds (Fig. VI.1.). However, the composition of unworked broken pieces found in these furnaces demonstrates levels of antimony oxide (approx. average of 0.5 wt%) and manganese (approx. average of 0.2 wt%) which may suggest re-melting of various batches of mixed or recycled glass rather than a preferential use of unaltered imported raw material. This working practice is well attested in other Roman secondary workshops (e.g. Freestone et al. 2015b). In the case of the Serdica furnace, certain differences between the compositions of the four analysed chunks suggest mixing of glasses with various chemical makeups in one melt which was only partial homogenised. Additionally, a moil fragment (SER 18) found immediately next to the furnace clearly differs from the chunks. Its dissimilar Sb–Mn ratio and trace oxide pattern point towards a likely addition of cullet to the batch rather than the moil itself being contemporary working debris of the workshop (see Section V.2.6.).

The distinction outlined above between imported fresh glass and unworked debris from secondary workshops is an argument not to consider all the chunks as instances of unaltered primary compositions, and as a result, as direct evidence for inter-regional distribution. It seems that at least during the late Roman period (late 3rd – 4th c. AD) glass with mixed decolourising additives circulated in the Balkans which points to a pattern of glass mixing at regional level (see Section VI.2.2.1.), as observed also elsewhere (e.g. Foster and Jackson 2010; Jackson and Paynter 2015). Therefore, a more cautious approach is preferred here and only unworked chunks clearly resembling well-attested primary glass groups are discussed in regard to the inter-
regional distribution. The rest of the finds are tentatively linked to the circulation of glass among smaller scale networks within the Eastern Balkans.

**VI.1.1.2. Compositions of imported raw glass as indication of the inter-regional distribution networks reaching the Lower Danube region**

The studied site assemblages indicate that the main influx of primary raw glass to the region in Late Antiquity is formed of Mn-decolourised composition. It is generally dated to the 5\(^{th}\) c. (=Série 3.2. of Foy et al. 2003) and is followed by its successor, the 6\(^{th}\) c. composition (=Série 2.1. of Foy et al. 2003), the latter being well attested up to the very end of the early Byzantine occupation, i.e. the beginning of the 7\(^{th}\) c. This conclusion is based on the analysis of finished vessels which are broadly recognised as regional and/or local secondary production, characteristic for the overall usage of glass in the Lower Danube. These finds are discussed below in respect to the regional and local distribution networks (see Sections VI.2.3. and VI.3.). However, they are important also as an indirect clue (following a ‘retrospective’ direction of enquiry) about the compositions which formed the main supplies for the secondary glass-blowing workshops in the Eastern Balkans. Here, evidence from fresh raw glass chunks is less conclusive, as explained above, since they did not enter the archaeological record in quantities and appearance representative of their actual scale of distribution. Several unworked chunks of the 5\(^{th}\) and 6\(^{th}\) c. compositions are presented in the studied data set (SER 2-4, 9, 10, 13, 21, 22) which are cautiously related to the refuse disposal of the secondary workshops in Serdica (see Section VI.2.2.2.).

Both compositions prevalent in the Lower Danube in the 5\(^{th}\) and 6\(^{th}\) c. are well-attested in other parts of the Empire as well (see Sections III.2.4. and IV.2.2.). This supports their link to the primary glass production, ruling out a possible interpretation that they may have resulted mostly from mixing and recycling at regional level. Therefore, these groups provide the specific kind of “hidden’ evidence of long-distance trade” (Whitehouse 2003, 301) which is recognisable through scientific analysis and not immediately visible when using traditional archaeological approaches only. Identifying the geographical source of these compositions is still an open question but they both should be regarded as geochemically related to each other, and yet,
representing separate production groups (Cholakova et al. 2015). Any attempts to point to particular regions within the East Mediterranean coastline as places of origin of these groups (e.g. Foy et al. 2003; Ceglia et al. 2015) need to take into account a wider range of reasoning. A detailed awareness of the geological settings in the areas of primary glass production is essential for identifying departure points of the inter-regional networks which transferred these primary raw glass supplies to the Eastern Balkans. At the same time, the general trends and directions of long-distance trade to the Lower Danube should not be ignored.

Unfortunately, the present research cannot be entirely conclusive regarding the dominant overseas supplies of raw fresh glass to the studied region during the earlier period, i.e. end of the 3rd – 4th c. This is explained partly by the dating of the analysed glass assemblages, representative mostly of the later period, i.e. the 5th – 6th c. (Dichin, Odartsi), or by the selective sampling due to the complex site chronology (Serdica, see Section V.1.). Nevertheless, the above mentioned samples from the secondary tank furnaces in Serdica and Philippopolis tentatively point towards intense mixing of different glass compositions within the region prior to the end of the 4th c. – an observation which will be discussed below (see Section VI.2.2.2.).

Two more compositional groups, namely the likely continuum of Roman blue-green/ Levantine I glasses (Jackson and Paynter 2015, 6) and the HIMT glass, should be mentioned in regard to the inter-regional distribution networks. The import of raw glass of **Roman blue-green/ Levantine I composition**, similar to the primary glass produced on the Levantine coast, e.g. in Apollonia-Arsuf, (Freestone et al. 2008b) is attested with several chunks from Serdica (SER 1, 5-7, 11, 12) found in a disturbed late antique (5th – 6th c. ?) context. However, it seems that these consignments originally coming from the region of present-day Northern Israel were only a small fraction of the overall primary glass supplies to the Lower Danube. Accordingly, it is not possible, at least at the present stage of research, to ‘track’ their pristine composition in the repertoire of the regional secondary glass working, neither as debris nor as finished objects. The most probable reason for this is the inevitable intermixing of the imported primary glass, and hence – compositional blurring, which took place once they entered the regional networks of production and distribution. Quantitatively less presented,
the Roman blue-green/ Levantine I raw glass was most probably absorbed into the predominant overall volume of the 5th and 6th c. compositions. Presumably, no practical need or any other non-technological reasons would necessitate the separate re-melting of minor batches of these fresh chunks.

The distribution of the HIMT composition, supposedly of Egyptian coastline/ North Sinai origin (Freestone et al. 2005; Nenna 2014), in the studied region is a more complex phenomenon. No fresh chunks have been so far registered in the Lower Danube, except a single piece* from Novae found in disturbed late antique layers (Olczak 1998, 38, N111). However, apart from the finished HIMT vessels, a tentative identification of possible glass blowing waste of HIMT composition (i.e. G 17 – a lid moil) and likely malformed fragments with the typical yellow-brown/amber colour from Dichin (e.g. G 11; see Section III.2.3.; Cholakova 2009b, 263), strongly suggest the usage of primary HIMT glass in the Balkan secondary workshops. The hypothesis of a regional/ local manufacture of these vessels (or, at least of the majority of them) in the Eastern Balkans is commented upon below, in regard to the smaller scale distribution networks (see Sections VI.2.3.1.). At the same time, the supposition that the finished vessels were regionally made implies that during the 5th c. HIMT raw glass was at first traded along the long-distance Mediterranean routes, originally beginning at the Egyptian coastline, to eventually reach the Lower Danube secondary ateliers. Therefore, the HIMT composition is another alleged instance of ‘hidden evidence’ of inter-regional distribution, similarly to the predominant supplies of the 5th c. and 6th c. compositions discussed earlier. Nevertheless, the circulation of HIMT glass must have followed different models of intra-regional usage or consumers’ demands since the archaeological group of HIMT finished vessels stands out both technically and visually as quite distinct from the rest of the contemporaneous glass ware.

Finally, an attempt to juxtapose the relative amounts and chronology of the primary production groups imported to the Eastern Balkans as part of the inter-regional distribution networks demonstrates certain specifics. Acknowledging the

---

* The HIMT composition of the sample is not recognised in the original publication. However, the specific chemical makeup with 2.5 wt% Fe₂O₃, 1.7 wt% MnO, 0.7 wt% TiO₂, alumina of more than 3 wt%, and lime of about 6 wt%, and the dark-yellow colour of the chunk identifies it as belonging to the same glass group (Olczak 1998, Table 3).
inconclusive/ not representative character of the available finds for the period prior to the end of the 4th c., a diversity of fresh glass supplies is seen throughout the 5th c. As evident from the well dated contexts of this time in Dichin (AD 410-490), the Mn-decolourised composition (=Série 3.2. of Foy et al. 2003) seems quantitatively prevailing, but other supplies such as the HIMT composition and probably the Levantine I glass (raw chunks from Serdica) are also present in the assemblages. However, the finds from the second half of the 6th c. (Dichin, AD 540-580) and the very beginning of the 7th c. (Odartsi, by around AD 615) outline a different situation, with an almost exclusive domination of the 6th c. composition (=Série 2.1. of Foy et al. 2003). The latter is valid even if we consider the import of minor shipments of Levantine I glass. It is believed that such a pattern of change is not biased by sample selection or similar technical reasons, and the studied set is representative for the overall influx of raw glass during the 6th c. to the Lower Danube (Cholakova et al. 2015).

The contrast between the evidence of inter-regional glass supplies during the 5th c. and the 6th c. respectively, may arise from different factors. On the one hand, the continual predominance of the 5th c. and the 6th c. compositions and the likely geochemical closeness between both primary groups point to the existence of an established route for steady overseas distribution of raw glass to the Lower Danube. On the other hand, the parallel import of other compositions (HIMT, Levantine I) during the 5th c. may indicate a developed commercial market-type economic environment which accounted for different consumers’ preferences and was open to a diversity of the networks. The decline or even cessation of such parallel imports during the 6th c., as suggested from the present dataset, signifies an important change of the general structure of supplies which cannot be solely explained with a halt of the respective primary productions in the Eastern Mediterranean. Not much can be stated with certainty about the exact chronology of the HIMT primary production, but in the 6th – 7th c. the tank furnaces in Apollonia-Arsuf were clearly producing Levantine I raw glass on a large scale (Tal et al. 2004; Freestone et al. 2008b). However, this glass did not reach the Lower Danube anymore. Therefore, a change in the economic mechanisms underlying the inter-regional distribution networks of the Lower Danube looks as a plausible, even if only hypothetical explanation of the observed changes.
Such a speculative interpretation may be augmented with historical evidence for the establishment of Justinian’s *quaestura exercitus* (AD 536) as an unique administrative unit aimed at securing the supplies and financial support for the threatened Lower Danube frontier of the Empire (see Section I.2.1.; Cholakova 2014; Torbatov 1997). The situation in the region during the 6th c. – an overall political instability, a certain shift in the ethnic pattern of the population, changes of the settlement model and many others, finally lead to economic decline and possibly to the collapse of the commercial market-type long-distance distribution. The intervention of the state, marked by the creation of the *quaestura exercitus* may have contributed to a probable centralisation or even monopolising of the overseas shipments to the Lower Danube, resulting, as a side effect, in the circulation of a single prevailing glass composition to the secondary workshops in the region. It is widely acknowledged that the interests of the late antique Empire in such situations primarily concerned the *annona militaris* supplies for the army (traceable through amphorae finds, e.g. Karagiorgou 2001; Curta 2016), and certainly glass would not be a commodity of strategic importance in such case. However, a commercialised distribution of raw glass bound to the reliable state-lead long-distance networks (see Section I.3.) is a quite possible scenario for the Lower Danube in the 6th c., even though it would not be a really independent market-type supply. Therefore, the proposed interpretation of the present data is a transition from proper commercial and diversified inter-regional networks of the 5th c. to the mostly state-dominated long-distance merchandising of the 6th c. to the region. Whether this transition affected or not the overall volume of the imported primary glass is a challenging question which will be discussed further in regard to the glass recycling within the region (see Section VI.3.2.2.). In any case, no evidence for a reduced use of glass vessels is seen in the 6th c. contexts of the studied sites.

**VI.1.2. Inter-regional distribution of finished vessels**

The following sub-section concerns the examples of glass vessels which are differentiated from the repertoire of the regional/ local secondary workshops in the Lower Danube. Based on a number of specifics, these finds stand out from the range of
vessels commonly produced in the region; they are defined as imports which were manufactured and originated as finished objects from another region, regardless of the compositional provenance of the primary glass they were made of.

**VI.1.2.1. Inter-regional movement of goods based on examples of finished glass vessels**

Long-distance distribution of finished objects is neither identical with, nor contradicting the circulation of fresh raw glass but it sheds light on different socio-economic phenomena. The raw glass supplies were aimed to reach regional and/or local secondary glass manufacturing centres, rather than the places and settings of usage of the finished glass objects; obviously such a semi-finished material would have been worthless in dwelling or church spaces. At the same time, the movement of finished vessels was not linked to the needs of an industry, but to the characteristics of ordinary consumption in its various contexts and levels (private domestic, public, religious, funerary, etc. Lavan et al. 2007; from everyday household to elite luxurious levels). Accordingly, if the distribution of raw glass to the Lower Danube illustrates certain trends in the mainstream long-distance commerce (being an example of independent market-driven enterprise, or economic activities subordinated to the state-dominated distribution; see Section VI.1.1.2.), then the import of finished vessels to the region may reflect not only trade as market-type exchange, but also other possible kinds of socio-cultural processes. Hence, distinguishing between the influx of raw glass and deliveries of vessels manufactured in secondary workshops outside the Eastern Balkans is a significant aspect of the research which reveals certain nuances of meaning and interpretation.

The identification of inter-regional distribution networks of fresh glass is based mostly on analytical data and indirect ‘hidden’ evidence, as discussed above, and only a few compositional groups are found relevant to it. In contrast to this consistency, the inter-regional import of finished items demonstrates much wider diversity and is recognised both by the vessel morphology, style, and manufacturing/decorating techniques, and by the chemical makeup. Moreover, certain glass compositions (e.g. HIT, Sb-decolourised glass) observed in such imported vessels are sharply identifiable
within the overall volume of glass in use in the Lower Danube, showing no blurring which may be expected at the level of the intra-regional secondary industry, particularly in areas situated away from the major centres of the Empire. The superior quality of vessel manufacture and finishing is another argument to assume that these finds were produced in workshops with higher technical standards, located outside the provincial Lower Danube region.

**VI.1.2.2. Patterns of distribution of imported finished glass vessels in the Lower Danube region**

As pointed out above, the current dataset indicates a significant diversity of vessels (respectively, of compositions) imported as finished objects to the studied region. This may be a reflection of a likely multiplicity of the geographic directions, and, on the other hand, of the variety of underlying reasons for the movement of these items. It is commonly acknowledged that finished vessels ‘did travel both as objects in their own right and as containers...’ (Whitehouse 2003, 301). In the latter case the actual product of distribution was the content (small amounts of food or cosmetic substances, liturgical substances from Christian sacred places, etc.), and a practically reasonable assumption is that its glass package must be a closed vessel shape, with a stopper or lid. For open tableware vessel shapes it seems more probable that they were distributed just as items for usage by themselves, often representing high quality luxurious production intended for more elite levels of the consumer spectrum. The movement of glass oil lamps may have been linked to the religious context of their use as lighting devices in churches, and the role of pilgrimage and movement of pilgrims’ donations/ mementoes (Keller 2010). In other cases, glass vessels were certainly distributed simply as personal possessions, or as gifts indicating social hierarchies, as symbols of status, or of patronage-like types of relationship (Garnsey 2010; Garnsey and Woolf 1989; Price 2000, 21).

Such diverse kinds of mechanisms of movement imply that commercial profit-driven motive and market logic were not necessarily involved here, but that often non-commercial reasons determined these networks, resembling Polanyi’s concept of reciprocity and re-distribution (Polanyi 1944; see Section I.3.). Recognising both types
of processes in the inter-regional glass vessel distribution is an important but not always/ easily achievable aim when archaeological material is studied. Certain approaches, such as the single batch evaluation can help to identify smaller one-off deliveries which had probably the character of non-commercial transactions (Price et al. 2005), as opposed to the larger-scale steady flow of regularly traded finished vessels. However, there are no firm arguments to assert that these were totally unrelated long-distance networks since more or less the same communicational infrastructure must have served both of them. Furthermore, a certain blurring of the socio-economic mechanisms is possible, especially when vessels once commissioned from far afield entered the smaller regional networks at a later stage.

The following summarised overview is an attempt to interpret particular examples of vessels and glass compositions from the studied dataset, delivered through inter-regional networks to the Lower Danube, in relation to the likely purpose and mechanisms of their distribution.

The antimony-decolourised glass composition with little or no traces of admixture, i.e. containing only insignificant amounts of manganese, is often considered as a makeup of superior quality preferred for the elite vessel manufacture (e.g. Foster and Jackson 2010; Sayre 1963). Only three samples from the studied set definitely belong to this compositional group (G 84, SER 28, SER 52), and they all demonstrate low concentrations of sand impurities, as typical of this primary group. The preserved engraved decoration of SER 28 defines the vessel as a luxurious item; the plain base fragments G 84 and SER 52 are carefully manufactured but they are too small to be indicative. These finds were certainly imported to the region as finished products, probably traded as high-status commodities, and/ or maybe distributed for non-commercial reasons (i.e. as valued personal gifts). They are all found in late 4th – 5th c. contexts, and the parallels of the SER 28 decoration dated to the same period indicate that it is not a case of heirloom (see Section V.2.3.). Hence, these vessels, with their insignificant number in the overall studied set confirm the decreased use of antimony decolourised glass, however still in production by that time.
With certain stipulations, the analysed cage-cup from Serdica (SER 26 & SER 27) may also be included in the same group, even though clear signs of partial use of recycled material separate its base colourless glass from the rest of the antimony-decoloured samples. This vessel is a special case representative of the highest levels of the late antique glass working. The technological aspect of the find was already commented upon (see Section V.2.3.), but a brief remark regarding the distributional pattern of *diatreta* is needed as well. It has been already noticed that their main concentrations are along the northern frontier on the Rhine and the Middle Danube (Meredith 2009, Fig. 13.2.). It is beyond any doubt that *diatreta* are elitist items, knowing that many of them, similarly to the analysed cup, come from rich burial contexts (e.g. Dimitrova and Popov 1977; Harden *et. al.* 1987, N135). With their production situated within the distributional context of other contemporaneous high-ranked goods, such as the fourth-century brooches used as *ornamenta dignitatis* (Popović 2007), it is quite likely that the circulation of cage-cups was not a market-driven economic process, but that certain socio-political motives determined, at least partly, these networks. Similarly to the other late antique *largitiones*, these precious vessels could serve as gifts allocated by the imperial administration (*comes sacrae largitiones*), or by the nobility (Spier 2010). Such a hypothesis is indirectly supported by the distribution of other luxurious late antique glass finds from the Lower Danube (e.g. a cage cup – Shepherd 1999; a gold glass vessel base – Pillinger 1984; an engraved figured dish – Milčheva 1999) which indicates the likely existence of a relevant social milieu at the recipient-end of the inter-regional non-commercial distribution networks in the region. At the same time, not much can be stated regarding the geographical directions of these imports since here the question about the origin of the Sb-decolourised primary glass (Egypt?) is not the leading one, but the main problem concerns the location of the secondary workshops which fabricated the objects.

Another clearly distinguishable set of finds are the **HIT composition** vessels (G 1-3; G 28, G 60, G 61). These are known in the Dichin assemblage only, and, according to the published data, have a very few known exact parallels of their chemical makeup
within the overall vessels glass range*. The observation of the archaeological study that these finds stand out as quite an uniform group within the assemblage, tightly dated to a relatively short period (AD 470-490) raised a hypothesis that this was a case of single delivery to the site, rather than evidence of regular prolonged trading (Cholakova 2009b). The chemical analyses confirmed this assumption, reinforcing it by the identification of two vessels coming from a single glass melting episode (Rehren and Cholakova 2010). The composition with elevated iron oxide and titania and the trace oxide pattern suggest an Egyptian origin of the primary glass. However, this consignment of vessels must have originated from a particular secondary workshop supplied with a rare type of Egyptian fresh primary glass, most probably situated outside the Lower Danube but not necessarily in Egypt. The quality of the HIT vessels manufacture demonstrates a very good level of craftsmanship even though the finds should not be seen as luxurious. Given the current lack of a substantial amount of vessel glass of the same composition from elsewhere, a non-commercial type of distribution (dedicated supply?) seems more probable, and it may cautiously be linked to the social status and relationships (patron-client type?) of the community occupying the site at that time.

A similar case, again known only from the Dichin assemblage, is a set of bowls Isings 116 made of pristine Levantine I glass, dated to AD 410-470 (G 25-27, G 29-32). The vessels in this group are closely linked not only by their morphology and manufacturing style, but also by their chemical composition, with clear indications that the bowls could have come from one or two batches of glass melting (Rehren and Cholakova 2014). The engraved decoration with Christian symbols suggests an East Mediterranean (Syrian, Levantine?) place of manufacture of the vessels, in accordance with the Levantine origin of the primary glass. Most likely, this is a one-off supply to the site, comparable in its interpretation to the slightly later HIT vessels. However, unlike the HIT group which stands out as compositionally and, to a certain extent, typologically uncommon at least for the region, the Levantine I bowls from Dichin fit in

---

* A recent publication on late antique glass from Cyprus identifies single sample with no intentionally added colorants as HIT composition, unfortunately not precisely dated (Ceglia et al. 2015, sample ID821). Several other examples of HIT glass are known so far but all of them are coloured glasses (see Section III.2.2.).
a widely distributed range of similar vessels known in the Balkans and beyond (see Section III.2.1.). Hypothetically, their general spread could have been a regular commercialised inter-regional flow from the Levant to the Balkan provinces during the 4th – 5th c. At the same time, the particular group of bowls delivered to Dichin on one occasion may represent an instance of a single purchase, or rather a localised sub-distribution regulated by non-commercial reasons (symbol of social status?) – i.e. a possible example of blurring between the levels and mechanisms of functioning of the distribution networks.

A single sample from the current dataset is tentatively linked here to an earlier phase of the same long-distance distribution network from the Levant. A deep bowl (SER 24) is made of manganese decolourised variety of Levantine I composition and comes from a late 4th c. context in Serdica. Although it represents an isolated example in the studied set, the vessel is exceptional neither by its chemical composition nor by its morpho-typology and manufacturing technique. Numerous finds provide analogies of its features (thick-walled vessels; cold glass working; occasional blue blobs – see Section V.2.1.) demonstrate a steady inter-regional distribution of such tableware/ lamps to the Lower Danube, the Balkans, and beyond during the 4th c., explainable as commercialised trade. The research on the contemporaneous production centre at Jalame, Northern Israel (Brill 1988; Davidson Weinberg 1988) strongly supports the assumption that both the primary glass melting and the secondary vessel manufacture occured on the Levantine coast, even though the fashion of such cups and bowls was certainly adopted in the late Roman Western glass ateliers as well (Harden et al. 1987, 102-103).

The Mn-decoloured composition (=Série 3.2. of Foy et al. 2003) was already discussed as being probably the predominant primary glass type supplied as raw material for the regional workshops in the Lower Danube during the 5th c. However, the same composition was certainly traded to other areas of the Empire, where

---

* The vessel type is quite popular in the region but there are no available analytical data to confirm the Levantine I compositional identification for these finds.

** A possible explanation of having only a single vessel of the 4th c. Mn-decolourised Levantine I glass in the analysed set is provided by the chronology of the studied assemblages: Dichin and Odartsi cover mostly the later period of early 5th – early 7th c. AD, hence it is very liekly that the earlier compositions are quantitatively underrepreversed.
different secondary workshops manufactured vessels according to their respective regionally adopted and developed styles and techniques. Therefore, import of finished vessels of the same 5th c. Mn-decoloured glass produced in centres outside the Eastern Balkans could be expected. The thorough comparison of the archaeological features and compositional data allows recognition of a likely case of such inter-regional import as a single production/supply episode in Dichin assemblage, tentatively dated to ca AD 470. The samples G 18 and G 19 are analytically indistinguishable within the limits of the EPMA method (Fig. VI.2.A, B). However, these two very similar but still separate objects (Fig. VI.2. – bottom) both stand out from the rest of the 5th c. Mn-decolourised vessels in the current dataset by their elaborate decoration, and hence are interpreted as a set of high-quality tableware procured from further afield. Most probably, it is another case of inter-regional distribution (from the Eastern Mediterranean?) to the Lower Danube which followed market-driven trade routes, or/ and it traced non-commercial social-related phenomena like gift-giving within the particular context of Dichin.

A few more examples among the studied materials illustrate similar events of
long-distance travel of finished vessels to the Eastern Balkans, presumably for occasional non-commercial reasons. The primary HIMT composition known as one of the widely distributed groups of Late Antiquity was used as raw material in the regional secondary workshops (see Section VI.2.3.1.) but also was sporadically imported as finished objects. A fragment of an oil lamp with massive pointed base (SER 35) comes from a context with uncertain 6\textsuperscript{th} c. date in Serdica. Without doubt, this is a HIMT vessel but its characteristics differ from the main group of the 5\textsuperscript{th} c. HIMT objects manufactured in the Lower Danube area, and from the vessel morphology of the regionally produced pointed lamps. There is no reason to assume that such a single atypical find represents a well-established inter-regional trade. A more plausible scenario explaining the presence of SER 35 would be the interpretation of the fragment as a particular movement of an individual item, probably linked to the religious context of use/ritual function of oil lamps (Keller 2010).

A similar interpretation as an example of long-distance distribution of single finished objects on particular occasions is possibly applicable to a bowl fragment from Serdica (SER 25) and a small flask from Odartsi (ODR 35), the latter being an exception in terms of its glass composition (see Sections V.2.7.; IV.2.3.). The bowl from Serdica could be quite tentatively related to the specific vessel style of the facetted glass distributed across the Danube frontier in the late 4\textsuperscript{th} – early 5\textsuperscript{th} c. contexts of the ‘Chernyakhov’ culture and further in the Barbaricum zones in Europe (the so called ‘Kowalk’ beakers; Gomolka-Fuchs 1999, Abb. 6; Gavritukhin 2011), while surprisingly, its composition resembles the later 6\textsuperscript{th} c. glass.

The flask from Odartsi demonstrates a peculiar trace oxides pattern (low SrO concentration), and its overall composition is similar to the Egypt II primary glass, a natron glass of a later date (Freestone 2006; Freestone \textit{et al.} 2015a). Taking into account the vessel shape, i.e. a small bottle with narrow mouth and short neck, and the moderate quality of its manufacture, it may be suggested that ODR 35 represents a rare case of inter-regional distribution of a special substance packaged in a mass-produced glass vessel, rather than a movement of the vessel as a valued item in its own right. However, it should be noted that a small early medieval settlement (from the late 8\textsuperscript{th} – early 9\textsuperscript{th} c. to the first half of the 11 c.) emerged from the ruins of the late
antique fortress at Odartsi (see Section IV.1.1.; Torbatov 2002a, 11). Therefore, the small bottle made of glass close to the Egypt II group found at Odartsi may represent an exceptionally early (mid 20s of the 7th c. at the latest) example of this composition. Alternatively, it should be assigned to the medieval period of occupation. Considering the disturbed context of the find, most likely the sample ODR 35 could be linked to those later phases of the site. Therefore, it illustrates a chronologically later long-distance network for distribution (and probably, re-distribution) of substances with special importance or function. It can be assumed that such a network was not necessarily commercially driven. Glass of Egyptian origin is indicative of the direction of the network. However, the vessel had only a role of package while the actual product intended for transportation was its content.

Finally, two more samples from Serdica are worth mentioning in regard to the inter-regional circulation of finished glass vessels. Two stemmed goblets (SER 44, 45) found in inconclusively dated late antique contexts stand out from the rest items in the assemblage not in terms of morpho-typology but because of their chemical composition. Both samples demonstrate unusually elevated potash, magnesia, and phosphate concentrations for natron glass. The technological aspect of these samples brings out the question about the spread of plant-ash based glasses (see Section V.2.7.), also discussed in regard to similar finds from the 6th c. Central Balkans (two unworked chunks – Drauschke and Greiff 2010). However, in the setting of distribution networks, SER 44 and SER 45 indicate that at that moment an extrinsic composition was present in the Balkan context, generally dominated by standard natron glass (i.e., the 6th c. composition). Such finished vessels could have been brought to Serdica as imports, commercialised or not, but most probably were produced in a secondary workshop outside the studied region.

The summarised evidence of inter-regional distribution of finished glass vessels in the studied dataset points to a diversity of imports to the Lower Danube which not always mark commercial activities or trade. It seems that non-commercial mechanisms of distribution played an important role for the long-distance movement of objects. These are not strictly economic processes since often the number of the imports is insignificant compared to the volume of inter-regional supplies of raw glass, for
example. However, being related to a variety of underlying reasons (from proclamation of socio-political relationships to religious pilgrimage or movement of personal possession), the non-commercial long-distance networks were more dynamic and diverse than the mainstream economic trends in glass circulation. At the same time, a parallel development of profit-driven inter-regional trading of finished vessels to the region certainly existed, and the Levant was one of its main departure areas.

Chronologically, it seems that the 4th – 5th c. networks were more developed and active, while the 6th c. inter-regional distribution of finished vessels can only be vaguely supposed. Knowing that the 6th – early 7th c. contexts are well represented in the studied dataset (Dichin and Odartsi assemblages), such a chronological peculiarity of the long-distance networks cannot be considered an effect of disproportional sampling. The analysed materials from the later period show decrease in inter-regional distribution of finished vessels, and very little or no evidence for commercialised trade at this level. This conclusion reinforces the interpretation of the inter-regional distribution of raw glass (see Section VI.1.1.) which demonstrates that in the 6th c. significant changes of organisation and probable disintegration of long-distance diversified networks of commercial market-type exchange took place. Such processes were evoked not only by the political and economic instability in the Lower Danube region at that time but also by notable changes in the consumers’ tastes and needs, reflecting the overall considerable ethnic and socio-cultural shifts at the end of Late Antiquity.
VI.2. Regional level of distribution networks

Circulation of glass, both as raw material and finished objects, within the Eastern Balkans/ the Lower Danube may not be immediately evident since it followed the less tangible and less explored internal overland distribution networks of the region. However, the routes of connectivity, exchange, and trade at this level are recognised as most important and indicative for the vitality of the regions (‘the prime mover’ of the late antique economy: Ward-Perkins 2001a, 169). The stability of this ‘medium-distance exchange’, illustrated for example by the regional distribution of certain groups of pottery, is seen as symptomatic for the overall socio-economic sustainability, and these networks are even contrasted to the long-distance luxury trade of mostly socio-political rather than economic significance (Wickham 1998, 282-283). In the case of glass distribution in the Lower Danube region there is no such opposition because the maintenance of the general resources of glass available within the regional environment relied upon the inter-regional supplies (see Section VI.1.1.2.). The present section discusses the internal distribution networks of the studied region based on available results from secondary workshops and indirect reasoning about regionally produced vessel groups.

VI.2.1. Summarised characteristics of the secondary glass manufacture in the Lower Danube region

Regional networks operated when the spread of the inter-regional imports continued further within the Eastern Balkans. At the same time, one of the leading functions of these internal chains was certainly related to the secondary glass workshops situated throughout the region: their raw material supply and distribution of the finished production. At present, evidence of this secondary manufacture is limited (Cholakova 2008). However, its characteristics are important because they define to a great extent the significance of the regional networks. Without going into detailed analysis, only a
few important points need to be outlined here. Firstly, in a broader chronological prospect, the beginning of the regional production of glass objects may tentatively be assigned to the 2\textsuperscript{nd} – 3\textsuperscript{rd} c. AD, without any direct evidence (furnace remains, working debris) clearly dated before the (late?) 3\textsuperscript{rd} c. AD (a summarised review of the available information is given in Section VI.3.1.). Furthermore, the Roman and late antique provinces in this part of the Empire never developed a secondary glass industry of major economic importance or artistic qualities. The glass workshop’ production in the Eastern Balkans was aimed to satisfy the needs of consumers of middle or lower social levels within the region but not those of the elite, and it was not meant for commercialised export of finished vessels to far afield. Taking this into account, as well as the geographical position of the Lower Danube at the margins of the Empire, it seems unlikely that the glass blowers in the region were proactive in requesting their raw glass supplies from particularly preferred primary production centres. Procurement of fresh chunks at the destination end of the inter-regional networks and probably a technologically and economically reasonable practice of cullet recycling characterised the regional glass vessel manufacture.

\textbf{VI.2.2. Circulation of unworked glass within the Lower Danube region}

The circulation of raw glass along the regional networks of distribution is a telling example of the interaction between overseas inter-regional distribution and trade on one hand and, on the other hand, further spread of goods to the final points of their use within the region. The following paragraphs present some general comments on this aspect of glass circulation in the Lower Danube, and summarise the available evidence.

\textit{VI.2.2.1. Unworked glass supplies along the regional networks of distribution – possible compositional modifications?}

Unfortunately, little is known of how the bigger shipments of fresh raw glass arriving as maritime overseas cargoes at the shores of the region were then re-distributed in smaller consignments to the inland secondary workshops. The
organisation of such subsequent intra-regional supply can only be hypothesised but a process of further partitioning of the primary inter-regional deliveries seems quite possible, considering the enormous volumes of raw glass loaded for long-distance distribution from primary production centres (e.g. 15-18 tonnes of raw glass chunks in the Ouest Embiez 1 shipwreck – Fontaine and Foy 2007).

Deliveries of fresh primary glass are thought to be the main source for maintaining the overall pool of raw material available for the regional/local secondary workshops, especially within a well-connected economic environment (regardless of the nature of the distributional mechanisms). At the same time, glass recycling and large-scale cullet collection/exchange/trade certainly had their importance in the regional industries, as evident from the well-known textual sources (Keller 2005) and various cases of preserved cullet deposits (e.g. Shepherd and Wardle 2009; Freestone et al. 2015b). It cannot be definitely stated whether the distribution of bigger shipments of pre-collected cullet had reached the economic level of inter-regional networks but certain hints about this may be found in isolated shipwreck cargoes (e.g. Iulia Felix shipwreck in the Northern Adriatic Sea from the first half of the 3rd c. AD, or considerably later the 11th c. Serçe Limani wreck of the Turkish Aegean coast – Silvestri 2008.; Bass et al. 2009). Furthermore, glass recycling does not necessarily indicate shortage of fresh primary glass or economic isolation and decline of a particular region. Multiple factors have to be taken into account in regard to this practice since technological benefits/disadvantages of re-melting cullet, balancing the production costs, organisation of raw material procurement, etc. were certainly considered by the ancient craftsmen. Moreover, recognising the difference between the patterns of selective and indiscriminate recycling needs attention as well (Jackson 1996).

Discussing the socio-economic and technological aspects of glass recycling is beyond the scope of the present work (recent contributions in Jackson and Foster 2014; Jackson and Paynter 2015; Freestone 2015; Schibille et al. 2016). However, the main implication of this phenomenon at the level of the regionally available glass for secondary vessel manufacture is a certain blurring of the glass makeup, as mentioned previously (see Section VI.1.1.1.). Mixed batches of pre-collected cullet (procured regionally, or from hypothetical long-distance supplies) re-melted together with fresh
imported primary glass is a quite probable modus operandi, and this may have led to various modifications of the glass in circulation in the Lower Danube area. Such possibly repeated practice and a certain degree of exchange of raw material between the secondary workshops within the region could have contributed to a compositional ‘blending’ that might have concealed distinct but quantitatively underrepresented glass groups (recently described as a ‘great big melting pot’ – Jackson and Paynter 2015, 16; see Section VI.1.1.2.). In general, batches used for object manufacture in the ateliers in the Eastern Balkans must have closely matched the makeup of the contemporaneous predominant imported fresh glass. However, slight alterations or significant mixing are plausible to assume as well. Therefore, as already mentioned, the discarded unworked glass in form of chunks or blowing waste found in the context of secondary production within the regional networks or tentatively related to it is discussed separately from the inter-regional raw glass imports.

VI.2.2.2. Compositions in circulation within the Lower Danube region based on examples of unworked glass

The secondary glass melting tank furnace excavated at the ‘MS 8-II’ site in Serdica provides an opportunity to study the original makeup of the glass used in the workshops at regional level. The four analysed chunks (SER 14-17) demonstrate a certain chemical variability which may be an effect of poor homogenising or of the amalgamation of debris left behind as a result of multiple operational cycles of compositionally similar but not identical batches. Nevertheless, the scientific data combined with stratigraphic evidence from the site clearly confirm that during the second half of the 3rd – early 4th c. (?) antimony decolourised glass displaying compositional evidence of mixing or adulterating was in circulation. A sample available from Philippopolis (PLD 1) reaffirms that such pattern was not an occasional or local feature of the Serdica workshop but most probably was typical for the secondary production within the whole region. The chunk from Philippopolis comes from the filling of a similar tank furnace dated to the second half of the 3rd c. or the 4th c. (Cherneva 2014; see Appendix A.8.). Additionally, a single chunk from a disturbed context in Serdica (SER 8) also belongs to the same compositional group. The chemical analyses of debris found in four secondary tank furnaces in Novae generally dated to
the 4\textsuperscript{th} c. point to a similar tendency of mixing (Olczak 1998, 76-87), but with manganese as prevailing colour-modifying ingredient, and an overall pattern of moderate levels of lime and iron oxide (Fig. VI.3.B.).

Although similar mixed glasses with both decolourisers present are well known from other regions of the Empire (see Section V.2.6.) a more cautious interpretation is suggested here – the chunks from Serdica and Philippopolis are considered as characteristic of the circulation within the region rather than being placed in the context of inter-regional raw glass supplies. Re-melting of mixed cullet seems the most likely technology to affect the Sb\textsubscript{2}O\textsubscript{3}–MnO ratio when both additives are within an approximate range of 0.1 to 0.5 wt\%. At the same time, the colourless or nearly colourless appearance of the melt would have been maintained if the craftsmen were able or needed to successfully keep the required redox conditions during the re-melting. Three pieces of blowing waste – two moils and a thread from a removal from the batch of a solid impurity – all made of visually identical glass (Fig. VI.3.A.) were

<table>
<thead>
<tr>
<th></th>
<th>Al\textsubscript{2}O\textsubscript{3}</th>
<th>CaO</th>
<th>Fe\textsubscript{2}O\textsubscript{3}</th>
<th>MnO</th>
<th>Sb\textsubscript{2}O\textsubscript{3}</th>
</tr>
</thead>
<tbody>
<tr>
<td>SER 14-17 (chunks; n=6)</td>
<td>2.30</td>
<td>5.83</td>
<td>0.64</td>
<td>0.15</td>
<td>0.58</td>
</tr>
<tr>
<td>PLD 1 (chunk)</td>
<td>2.64</td>
<td>6.26</td>
<td>0.49</td>
<td>0.46</td>
<td>0.42</td>
</tr>
<tr>
<td>SER 8 (chunk)</td>
<td>2.30</td>
<td>5.91</td>
<td>0.40</td>
<td>0.32</td>
<td>0.44</td>
</tr>
<tr>
<td>SER 18 (moil)</td>
<td>2.52</td>
<td>7.34</td>
<td>0.43</td>
<td>0.40</td>
<td>0.17</td>
</tr>
<tr>
<td>Novae – furnace 3, chunk</td>
<td>2.30</td>
<td>7.50</td>
<td>0.87</td>
<td>0.48</td>
<td>0.25</td>
</tr>
</tbody>
</table>

*Fig. VI.3. Examples of glasses with mixed antimony – manganese composition: A. Serdica, ‘MS 8-II’ site – three pieces of glass blowing waste found next to the furnace (only SER 18 was analysed); B. A comparison of the diagnostic oxide levels in the mixed Sb – Mn samples (the data of Novae sample after Olczak 1998, 83, Table 12 (P 148-a/88s).*
found next to the Serdica furnace. They indirectly confirm that a certain amount of cullet must have been used as raw material in this workshop. The analysed moil (SER 18) differs from the composition of the chunks found in the tank (see Section V.2.6.) indicating that it cannot be a leftover from the same batch. At the same time, the moil sample, interpreted as standard Roman glass with added manganese, is by itself an already recycled material, with both Sb$_2$O$_3$ and MnO present but in a different ratio (Fig. VI.3.B.). In this way, the studied sub-set of debris from the Serdica workshop strongly suggests that multiple reuse of cullet, possibly mixed with/ added to fresh raw glass had its place as an established working practice in the region. Such an inference is reinforced by the data from the Novae furnaces which may be tentatively seen as a later stage (during the 4th and up to the 5th c. – Olczak 1998, Table 9) of a gradual fading of antimony-introducing vessel cullet within the overall mass of glass in circulation.

Interestingly, none of the analysed vessel glass samples from the Serdica assemblage has the same compositional pattern as the glass from the furnace excavated at ‘MS 8-II’ . This may be due to the selective sampling, or because of the chronology of the contexts (i.e. sampled vessel glass comes from later contexts than the furnace). Nevertheless, such regionally ‘blended’ and possibly cheaper composition could have been preferred for occasional and on-demand window pane production”, as supposed for similar Roman furnaces elsewhere (Băeștean and Höpken 2009). Both furnaces from Serdica and Philippopolis were found not in areas of regular urban craft production but isolated in the context of large public and private buildings which certainly needed considerable material for glazing at the time of their construction in the late 3rd – 4th c. However, considering the abundant examples of vessel glass with such mixed Sb$_2$O$_3$ – MnO chemical makeup (recently published finds from the Western Balkans in Marić-Stojanović et al. 2015) the answer to the question about the purpose of production of Serdica and Philippopolis furnaces remains ambiguous. In any case, during the late 3rd – 4th c. the regional circulation of a variety of decolourised compositions affected by mixing of antimony oxide- and manganese-containing glasses

* The present project concerns vessel glass distribution, and only insignificant number of window panes are included and studied here. Verifying such a hypothesis remains an objective for future analytical work.
(possibly Roman blue-green glass as well) is apparent. The same pattern is observed elsewhere, e.g. in Britain, during the 2nd – 3rd c. AD, and a detailed study of the contamination (absorbed from furnace lining, blowing iron, fuel vapour, fuel ash) during recycling implies a gradual spoiling of the glass due to the repeated re-melting (Jackson and Paynter 2015; similar approach in Schibille et al. 2016). The samples from Serdica and Philippopolis do not demonstrate a considerable contamination; there is no indication in their composition of overly repeated glass recycling practice that would have been necessitated by economic factors, such as shortage of supplies. Therefore, these mixed glasses are tentatively seen as evidence for an optimised use and recycling of regionally available but still carefully selected materials, i.e. fresh raw glass, pre-collected vessel cullet, and production waste, for ordinary objects manufacture, quite likely for window pane production.

The 5th c. contexts in the Lower Danube are dominated by another kind of Mn-
decolourised glass, identical with Série 3.2. of Foy and co-authors (2003). As discussed above, this was probably the main long-distance supply of raw material for the secondary workshops in the region at that time. Accordingly, its intra-regional circulation/ re-melting/ recycling did take place, even though the current set of samples includes only four unworked chunks of 5th c. Mn-decolourised composition (SER 2, 3, 9, 10), found in disturbed late antique contexts in Serdica. It is unclear whether these chunks represent fresh imported primary raw material, or whether they are debris which has undergone re-melting in a secondary workshop in the region. A comparison of the pattern of indicative trace oxides shows that the finished vessels of the same composition (Fig. VI.4.A-C.) have very similar low levels of cobalt, copper, lead, zinc, tin, and antimony (in general less than 50 ppm; PbO content of ODR 36 is an exception) as the analysed chunks (Fig. VI.4.D.). This may imply that supposing the chunks are primary unaltered material, then the finished vessels are almost entirely made of the same kind of fresh raw glass. Alternatively, all the analysed samples should be seen as generally representative of the output of the secondary workshops, as finished production or debris, after the re-melting and certain adulteration/mixing of the original glass composition. The latter interpretation seems more plausible, considering that these vessels belong to the common mass production within the region (see Section VI.2.3.1.), and it is unlikely that such manufacture had relied on fresh glass supplies only. Without a certain knowledge of the background concentrations of the mentioned trace oxides in the glassmaking sands used for the Mn-decolourised glass, it could be assumed that during the 5th c. cullet recycling at regional level was either limited, or a quite attentive and selective technology. The virtual absence of antimony oxide is very indicative of dissociation from the previous tradition from the late 3rd – 4th c. of Sb-decoloured mixed glasses circulation within the region (Fig VI.4.B.).

However, the situation is different regarding the 6th c. composition (=Série 2.1. of Foy et al. 2003) which is chronologically the last glass group to dominate the overseas supplies and the intra-regional distribution in the Lower Danube. Four
unworked chunks\(^\ast\) of this group (SER 4, 13, 21, 22) were found in Serdica ('MS 8-II' site); samples SER 21 and SER 22 come from a well dated 6\(^{th}\) c. context containing a few kilograms of glass working debris (see Section V.2.5. and below Fig. VI.7.C.). When the same comparison of trace oxides levels in the 6\(^{th}\) c. glass is made (Fig. VI.4.E-H.), it becomes evident that the later composition seems far more ‘contaminated’ than the earlier 5\(^{th}\) c. Mn-decoloured glass. Such a pattern may be tentatively linked to differences in the glassmaking sands but an increase of (indiscriminate?) cullet recycling during the later period certainly played role as well. At the same time, the unworked chunks of 6\(^{th}\) c. group (Fig. VI.4.H.) contain relatively lower amounts of glass colouring oxides (mainly copper and lead oxides) than the analysed vessels (Fig. VI.4.E-G.). Although this juxtaposing is provisional because of the limited number of analysed chunks compared to the vessels, it could be indicative of more intense and repeated cullet re-melting that may have led to accumulating higher concentrations of colorants in finished objects. This is a probable technological practice of the secondary glass working at regional/semi-regional level, and mostly, within the smaller local networks of glass circulation (see Section VI.3.2.2.).

One of the striking peculiarities in the 6\(^{th}\) c. glass composition is antimony oxide found at trace concentrations of an approximate average of 160 ppm which differentiates this group from the earlier 5\(^{th}\) c. Mn-decolourised glass. Such levels are negligible in regard to intentional decolouring but at the same time they are well above the supposed background levels of Sb\(_2\)O\(_3\) in the glassmaking sands ('a few parts per million': Jackson 2005, 764; Sb<1.4 ppm: Brems and Degryse 2014, 79). The interpretation of this contrast between both glass groups is again in glass recycling and more specifically it may be linked to changes in the sources of re-used glass. It can be tentatively related to certain peculiarities of the primary production (i.e. incorporation of cullet in the batches of primary glass making – see Section IV.2.2.), or/and to the processes at the level of local production-distribution networks discussed below (see Section VI.3.2.2.).

\(^\ast\) Sample SER 22 measurements by LA-ICP-MS demonstrated certain heterogeneity of glass and it is presented with data from two separate ablation spots, SER 22(1) and SER 22(2), without averaging them to a single set of numbers.
The present sub-section outlines the main glass groups attested as production debris in the current dataset with regard to the compositional modifications at the level of intra-regional circulation. A pattern of technological and chronological changes from the late 3rd to early 7th c. points to a variable extent of alterations which reflected the dynamics of the regional secondary glass manufacture. The **Levantine I composition** is not recognised as a self-contained group here, and this conclusion resembles the paucity of Levantine I glass observed elsewhere (e.g. Foster and Jackson 2009). However, it is believed that a quite practical reasoning stands behind this phenomenon in the Lower Danube region. As already discussed, the Levantine glass was certainly distributed to the Eastern Balkans, both as fresh raw chunks and as finished vessels (see Section VI.1.1.2.). At the same time, being a smaller part of the inter-regional deliveries (at least in the unworked chunks shipments), this composition could be simply ‘masked’ or ‘diluted’ in the regionally available mass of supplies formed of various kinds of raw glass and cullet, rather than being re-worked separately in compositionally distinct batches. Therefore, the preferred interpretation of the formal lack of Levantine I glass is not related to factors such as ‘reason of taste’, ‘market availability’, ‘different consumers’, ‘aesthetics’ (Maltoni 2015, 8; Foster and Jackson 2009, 194-195), ‘cost’ and ‘quality of the technology’ (Nenna 2014, 186), or the slightly modernistic economic viewpoint of ‘competition’ of supplies (Freestone et al. 2002b, 173). Instead, amalgamating raw materials of different origin at the level of regional networks may be suggested as a common technological practice in the secondary workshops which concealed certain less abundant groups. Interestingly, the analysed dataset implies that the **HIMT composition** which is present almost entirely as finished vessels was somewhat detached from this trend in the Lower Danube (see Section VI.2.3.1.).

**VI.2.3. Regional production and distribution of finished vessels**

The problem of recognising the production of regional secondary workshops for finished glass vessels does not always receive much attention in analytical studies, probably as a result of the difficulties in addressing such a question only by means of
compositional analysis (Cholakova 2014). It is commonly acknowledged that, due to the two-stage model of the late antique glass industry, no ‘workshop-specific fingerprints’ in terms of chemical composition at the phase of secondary production should be expected (Freestone et al. 2002a, 258). At the same time, the vessel morpho-typology may demonstrate certain tendencies for unification and development of common styles, such as the early Roman ‘multiregional styles’ (Stern 1995, 94). This typological uniformity illustrates very similar or even identical vessel shapes being simultaneously produced and spread across different regions of the Empire during Late Antiquity, and it may impede attempts to outline individual secondary glass workshops and their own specific repertoires. Nevertheless, the underlying assumption about the late antique glass vessel manufacture is that utilitarian mass produced vessels for common usage had not been transported over long distances but were made in regional or local secondary workshops, not least because of the obvious practical reason of fragility of glass (Lightfoot 1989, 12, 39). When vessel glass site assemblages are studied, a certain degree of consistency and frequency of shapes or techniques of manufacture, finishing, and/or decoration could indirectly help to outline the production of particular workshops or a wider vessel manufacturing tradition of the area (e.g. for Thessaloniki: Antonaras 2010a). However, so far only occasionally are such reconstructions linked to chemical glass compositions (e.g. Cruz 2014).

VI.2.3.1. Fifth century manufacture of glass vessels in the Lower Danube region

As pointed out earlier, the late 3rd – 4th c. distribution of finished vessels (imported, or regionally produced) is only scarcely illustrated within the present set of materials. The regional circulation of Mn-decolourised Levantine I composition and mixed glass with antimony oxide above 1000 ppm is very probable for this period but at the current stage of research they cannot be associated with a particular category of vessels produced within the Eastern Balkans. As the Dichin assemblage indicates, by AD 410 when the occupation of this site started, these two compositional groups are not recognisable within the studied set of materials (except for a single base fragment G 67 made of mixed Sb-Mn glass, which could come from some unidentified late Roman context, or could be a heirloom; see Section III.2.6.).
Although the present study cannot suggest a comprehensive explanation, during the 5th c. certain general changes must have occurred at multiple levels of the overall glass distribution and vessel manufacture in the region. The Mn-decolourised glass (Série 3.2. of Foy et al. 2003) appears to be the most abundant long-distance supply of fresh raw material as evident from the distribution of common tableware and oil lamps likely manufactured in the secondary workshops in the Lower Danube region. The glass finds from the first site period of Dichin (AD 410-490) provide definite evidence of this trend in the 5th c. Although distinguishing between the vessels imported as finished objects and those made of the same glass composition in ateliers situated within the region may be uncertain (Nenna 2014, 189), some particular characteristics of the finishing techniques are indicative of the craft tradition in the Eastern Balkans. Some features of vessel manufacturing of the Mn-decolourised composition can be outlined despite the challenges provided by the complexity of the processes of style evolution and transfer in late antique vessel glass, and the necessity of their clearer understanding in the modern archaeological research.

Firstly, the inter-regional import of luxurious finished vessels produced of 5th c. Mn-decolourised glass was already suggested (see Section VI.1.2.2.), and certainly the bowls G 18 and G 19 with engraved/ abraded decoration cannot be isolated examples of such objects brought to the Lower Danube, probably from the Eastern provinces. During the 5th c., various regional traditions of vessel production used the same primary glass group in their respective most recognisable techniques and styles, e.g. the mould-blown bowls with relief base ornament from Southern France (Foy et al. 2003, 69; Foy et al. 2010). The secondary Balkan workshops were involved in the general processes of spread, reproduction and modification of vessel glass trends and no sharp boundaries can be outlined for their own specific repertoire. However, a broad category of tableware (bowls) and possibly beakers/ oil lamps produced of 5th c. Mn-decolourised glass and decorated with trails of blue glass on the rims stand out as a technologically consistent group which might be interpreted as a particular manufacturing tradition of the region. The main vessel type within this category – bowls with fire-rounded rims is not by itself unique or displaying an exclusive distribution in the Balkans. Similar examples are known from the broader region of the
Mediterranean, and it seems that such shapes represent an example of ‘international’
genre in vessel glass (e.g. Fünfschilling 2009, Fig. 3:12; Cruz 2014, 59), regardless of the
kind and provenance of raw glass used in their manufacture. However, the finds from
the Balkans are quite distinct because of their decoration of blue trails marvered or
semi-marvered in the vessel walls, fire-rounded rims and use of pontil, as well as
because of Mn-decolourised composition established for all analysed vessels (G 54-59;
SER 49-51; SER 54-57; ODR 36). The 5th c. contexts from Dichin demonstrate that this
group is well represented quantitatively. At the same time, fragments from similar
vessels are known from other sites in the Balkans (e.g. Adam-Veleni 2010, N376; Fig.
VI.5.), including small settlements of local significance only* that would have hardly
been supplied with long-distance imports.

Therefore, the consistency of the chemical glass composition used, the specific
technique of decoration, and the pattern of region-wide distribution even to sites with
modest economic potential indicate that the vessels of 5th c. Mn-decolourised glass
with blue trails are probably representative of the secondary manufacture within the
Southern Balkans. The spread of this group is linked to the regional networks of
distribution (more likely as a commercially driven movement of goods), as well as to
the aesthetic tastes and preferences at the provincial level of an ordinary to middle
rank consumption. However, the finds cannot be attributed to a single workshop and
no particular regional production centre can be suggested at the present stage of

* More examples of bowls decorated with blue trails come from a small 5th – 6th c. fortified site near
Teteven, Western Bulgaria (Lazarov 2009, 447).
research. The most likely explanation would be that several secondary workshops in the region shared common raw material supplies, followed an unified manufacturing style, and served the same markets and users’ demands, exceeding the smaller scale local networks but not reaching the level of intended inter-regional trade.

Another example of the region-wide vessel glass distribution is well recognised in the present dataset. During the 5th c. and probably starting from the (late ?) 4th c. beakers and cups/bowls made of **HIMT glass**, often decorated with blobs of dark blue glass or mould blown with a honeycomb pattern are quite popular and they occur at nearly every site at that time from the Eastern Balkans (e.g. Fig. VI.6.A.). Their spread is similar to a certain extent to the distribution of the contemporaneous Mn-decolourised bowls discussed earlier, mostly because of the ubiquitous presence in various consumer contexts, from urban and semi-urban centres to remote rural areas in the Lower Danube (G 4-17, G 34-37, G 39-42, SER 29, SER 30, SER 46, ODR 41, ODR 43-46). At the same time, the HIMT vessels are quite distinct with their simplified morphology and the specifics of manufacture (cracked-off and cold-worked rims, no use of pontil, etc. – see Section III.2.3.). Differences between both technological styles – of the Mn-decolourised and the HIMT production, define them as two parallel but separate regional craft traditions. A slight chronological divergence between the two is very likely, with an earlier emergence of the HIMT glasses and a likely predominance of the Mn-decolourised vessels towards the end of the 5th c. Moreover, it seems that there is a quantitative prevalence of fragments belonging to Mn-decolourised composition in the 5th c. contexts (e.g. at Dichin, Serdica), where examples of both groups occur together.

On the other hand, unlike the colourless bowls with blue trails, the repertoire of the HIMT vessels from the Eastern Balkans belongs to a much wider setting of a remarkably unified vessel glass group. Nearly identical cups and beakers, invariably made of HIMT raw glass are found in the 5th c. in numerous regions of the Empire and beyond (e.g. Fig. VI.6.B.; see Section III.2.3.). At first sight, such a pattern of wide distribution contradicts the idea that the HIMT vessels in the present dataset belong to the regional level of production in the Lower Danube. The striking similarities between finds from distant regions could be possibly seen as an imperial-wide export from a
hypothetical large-scale vessel producing centre which has been supplied exclusively with raw glass of HIMT composition. Nevertheless, stronger reasoning would be certainly needed to speculate about a single major manufacturing centre (or a tight group of closely linked far-reaching ateliers) which suddenly ‘flooded’ numerous provinces of the Empire with standardised mass production bearing distinctive appearance but displaying fair to modest level of quality and craftsmanship.

The present study does not definitely reject the interpretation of the peculiar 5th c. HIMT vessel manufacture and distribution as a global economic phenomenon of inter-regional scale. Quite possibly, the bowls with honeycomb pattern which were popular but not abundant in the Lower Danube (the small fragment ODR 45 is the only example in the analysed set) arrived as occasional supplies from the Eastern Mediterranean (see Section IV.2.1.). However, the shaping of the majority of the studied HIMT fragments (irregular rims, often unworked, large bubbles in the vessel walls) does not reveal high craftsmanship. Moreover, the fact that these vessels are found in various contexts, including remote sites as Samokov (see Appendix A.8.) indicates that they were regionally well available/affordable. Taking into account the possible glass blowing waste (G 17, G 11 – see Section III.2.3.) it can be suggested that
a certain (considerable?) part of this production came from secondary workshops within the region, and was distributed within the regional networks and markets.

The close similarities between the finds from the Lower Danube and the HIMT vessels found elsewhere in the Empire and beyond should probably be placed in the context of dynamic changes (movement of ethnic groups?) during the late 4th – 5th c. These processes inspired the development and reproduction of common fashion and aesthetic preferences (respectively, common craft traditions) in various sections of material culture, e.g. costume, jewellery, as well as possibly in the vessel glass repertoire.

Finally, as already mentioned, the HIMT vessel glass diverged from the overall trend toward mixing re-used and fresh raw materials of different composition at the level of secondary glass working in the studied region (see Section VI.2.2.2.). The analysed dataset does not provide firm indications of blurred ‘in-between’ compositions which could be interpreted as amalgamated recycling of HIMT and Mn-decolourised glass (with only two possible exceptions, SER 31, SER 55; see Section V.2.4.). A technological practice of careful cullet selection and sorting prior to re-melting is the immediate explanation here. The distinct visual appearance of the HIMT fragments certainly allowed an easy separation of the cullet.

However, the studied assemblages do not provide any examples of combining, for instance, HIMT chemical composition with decoration of trails and/or fire-rounded vessel rim* which indicates that there must have been more profound differentiations between the main manufacturing traditions, respectively – their raw material procurements, in the Eastern Balkans. The simple technicalities of cullet sorting certainly played role but it seems that it was mostly the ‘non-technical’ aspects of vessel manufacture that kept apart both crafts traditions (i.e. the 5th c. Mn-decolourised- and HIMT-based vessel making). Acknowledging the intricate ethnic pattern of the region during the 5th c. (see Section I.2.1.), tentative links between certain fashion and workmanship of vessel glass and consumers’ tastes of particular

---

* This observation is valid for the studied region. When looking further West, in South-Eastern France and Iberian Peninsula, 5th c. bowls with fire-rounded rims and trails made of HimT glass are well known (Foy et al. 2003, Fig. 7, VRR182; Cruz 2014, 65).
groups of provincial population (foederati communities ?) may be seen in the case of HIMT production. Nevertheless, the attempts to unravel various technological styles of Late Antiquity, not only in glass manufacture, within the context of ethnicity always bring more questions than definite answers (e.g. Poulter 2013, 378) because of the complex processes of socio-cultural influences and transfer of artistic preferences and skills.

The present sub-section summarises main evidence of vessel manufacture in the Lower Danube during the 5\textsuperscript{th} c. which exceeds the local level of usage but has a region-wide significance. The Mn-decolourised and HIMT compositions form the essential supplies for the regional workshops, demonstrating two parallel styles of secondary glass working. Such a conclusion is based mostly on indirect arguments from the distributional patterns of certain groups of glass ware. Following default logic, the commonly used mass produced vessels in the setting of late antique provincial economy should be related to the activity of the neighbouring glass ateliers rather than to long distance inter-regional imports.

\textit{VI.2.3.2. Sixth century vessel manufacture in the Lower Danube region – identification of region-wide networks?}

A considerable shift in the raw glass supplies to the Eastern Balkans is observed during the 6\textsuperscript{th} – very beginning of the 7\textsuperscript{th} c. (see Section VI.1.1.2.). The predominance of the 6\textsuperscript{th} c. glass composition (=Série 2.1. of Foy \textit{et al.} 2003) toward the end of Late Antiquity in the region coincides with significant changes in the repertoire and functions of the vessels. Standardised techniques of manufacture (use of pontil, fire-rounded rims), rarely used and uncomplicated decoration (e.g. optic blown ribs, impressions on the flat lower part of small handles – G 52, ODR 33, ODR 50), and an overall trend for vessels produced/ decorated through one-off hot glass working manipulation (Price 2000, 22) are very characteristic of the craftsmanship of the period. The overwhelming majority of the vessel shapes belongs to the functional category of lighting devices\textsuperscript{*}, with a few main types of oil lamps (G 50-53, G 63, G 68-79; SER 32-34; SER 36-40; SER 43; SER 47; SER 48; SER 53; ODR 2-10; ODR 12-29; ODR 31-34; ODR 37-

\textsuperscript{*} Additionally, three pieces of window panes belong to the 6\textsuperscript{th} c. glass composition (G 38, G 70, G 87).
Tableware is rather uncommon (ODR 52, ODR 53) indicating changes of the consumers’ needs and probably an overall shift in the everyday household habits of the provincial population.

The suggested link between the geochemical characteristics of the 5th c. Mn-decolourised glass and the 6th c. composition in the present dataset has to be considered when trying to outline the origins of these changes. Most probably the succession of these two primary glass production groups resulted in continuity and a gradual shift from the earlier to the later raw fresh glass composition in the main supplies to the Lower Danube. Following the already established long-distance networks and traditional routes of economic connectivity, the import of the 6th c. composition became the leading and possibly the single source (as discussed in Section VI.1.1.2.) of fresh raw material for the secondary workshops in the region. However, the compositional shift of the overseas supplies could neither generate an abrupt change in the secondary workshops’ manufacturing techniques and repertoires, nor affect the consumers’ needs in these remote provinces. Parallel socio-cultural processes at the Lower Danube margins of the Empire gradually changed the ways in which glass vessels were produced and used. Apparently, the characteristics of the 6th c. regional vessel manufacture and distribution are rooted in a range of transformations (interlinked and/or coinciding) which still need to be better understood. Nevertheless, certain details in that bigger picture (e.g. the intermediate compositional sub-group of the 5th c. glass – see Section III.2.4.; continuous presence of same manufacturing style and certain vessel types in the 5th – 6th c.) indicate that the overall development should be seen as a gradual transformation of the socio-economic setting rather than as antithetical change and upheaval.

The reduction of vessel shape repertoire, as one of the aspects of the 6th c. transformation, leads to an almost total domination of a single type – stemmed goblets Isings 111, likely used as oil lamps – in all the studied assemblages. All of the analysed vessels are manufactured in a single hot working manipulation, using pontil.
Except for a few examples (ODR 1; SER 41, SER, 42, SER, 44, SER 45∗), they all are made of 6th c. glass composition, most probably in the Eastern Balkans secondary workshops (see Section IV.2.2.). Within such uniformity certain variations of the details are possible. However, this rather standardised secondary glass manufacture hinders the attempt to differentiate between the vessels produced and circulated at wider regional level, and the items made in smaller local workshops with limited economic potential.

Based on the above and with consideration of the identical vessel type and chemical glass composition commonly distributed within the Eastern Balkans, it seems quite possible that a process of merging of the regional and local networks took place during the 6th c. Nevertheless, such a conjunction may represent more than just a formal overlap, i.e. a result of the methodological limits of an artefact research anyway based on descriptive characteristics (morphological and compositional). The difficulty to formally distinguish between the regional and local glass distribution networks in the 6th c. most probably reflects real processes of transformation within the overall stagnant economy at the very end of antiquity in the Lower Danube.

A plausible interpretation of the present data is that the economic significance of the region-wide networks (i.e. with a radius of 100 – 300 km, Morrisson 2012a), respectively, of the manufacturing centres of regional scale, gradually diminished during the late 5th – early 6th c., and their functions declined. This is one of the numerous aspects of the general transformation in the Lower Danube at that time. Such a phenomenon is directly linked to the gradual reduction of the scale and importance of the urban mode of habitation in Late Antiquity in the Eastern Balkans (Dinchev 2001), since workshops of region-wide range certainly operated in the bigger cities/ provincial capitals (e.g. Serdica, Philippopolis; see Section VI.2.2.2.). Glass vessel manufacture and distribution in the region remained most active at the smaller level of local networks probably as a result of the decentralisation of the economic landscape towards the end of antiquity in the region. However, the overall process of significant transformations affected the smallest networks as well, probably increasing their

∗ Three cobalt blue examples of stemmed goblets (SER 23, ODR 11, ODR 30) are considered separately because of the alterations in the base glass composition caused by the colouring additive.
spatial and economic extent to a transitional ‘semi-regional’ level which superseded
the earlier region-wide networks (see Sections VI.3.1. and VI.3.2.2.).
VI.3. Local level of distribution networks and evidence of local glass working

The local level of distribution differs from the previously discussed inter-regional and regional networks not only by its spatial definition but also in terms of its economic meaning. This smallest scale of circulation of commodities covers areas of one, maximum two or three days travel by foot, within a radius of less than 50 km by land (Morrisson 2012a). It is representative of the distribution of most ordinary local production, such as agricultural and food staple, certain basic raw materials, or simple artisanal items manufactured in small workshops, often with only moderate levels of craftsmanship or quality of raw materials. Another peculiarity of the local distribution networks is the supposed non-essential role of professional traders or middlemen at this level where mostly producers and craftsmen took this part themselves (Morrisson 2012a). Without doubt, these networks have had their place in the late antique economy but tracing them may be still elusive. In the Lower Danube region it is plausible to recognise their transformation and growing significance in the context of the overall socio-economic fragmentation and political instability towards the end of the 6th – early 7th c. AD. At the same time, glass finds from that period demonstrate functional, morphological, and compositional unification (see Section VI.2.3.2.; Cholakova et al. 2015), implying rather complex processes.

VI.3.1. Secondary glass working in the Lower Danube during Late Antiquity; interpreting the distribution networks of local scale

The present sub-section provides a brief summary of the available information about the remains of secondary glass workshops in the studied region. This concise outline aims to relate the general discussion on the regional- and local-scale manufacturing centres and their distribution networks to the actual state of research and the
geographical dimensions of the Eastern Balkans. Furthermore, an interpretation of the
dynamic changes of vessel glass production and distribution at local level towards the
end of the period is suggested.

Unfortunately, so far there are only a few properly recognised, excavated,
reliably published and commented upon secondary glass workshops from present-day
Bulgaria (see Section I.3.2.1.). This overall poor evidence is partly due to the nature of
the traces of glass working visible in the archaeological record – furnaces are mostly
small-size, not often found/preserved, there is no abundant volume of production
debris, tools are quite an exception (Foy and Nenna 2001; Price and Cool 1991;
Shepherd 1999, 376-377). At the same time, when considered as a whole, the
information available until now indicates that from the late 3rd c. until the very early 7th
c. AD numerous secondary workshops existed within the Eastern Balkans (Cholakova
2008, 472). The approximate number of the known working assemblages is at least
twenty*. These finds reflect the presence of glass workshops which certainly varied in
their scale of operation, specialisation in particular categories of finished object
manufacturing (e.g. vessels, window panes, and jewellery), duration of functioning,
level of craftsmanship, etc.

Fig VI.7.A. gives an idea about the distribution of the evidence of glass working
activities during the 5th – 6th c. The problem of their more precise chronology should
not be ignored; certainly not all of the workshops indicated on the map operated
continuously and simultaneously during the entire period. Furthermore, it is
reasonable to assume that the assemblages identified here are only a fraction of all
workshops which had been functioning in the 5th – 6th c. Nevertheless, the map shows
a relatively dense spread of secondary glass working.

The geographical pattern in Fig VI.7.A. needs a complex interpretation when
turning back to the definitions of the spatial differentiation between local

* This number is a very conservative estimation based on published, partly announced, or available
unpublished information about furnaces, crucible fragments, working waste, unworked chunks, cullet
assemblages, and tools from present-day Bulgaria and parts of Eastern Serbia. Describing this quite
diverse evidence in the detail is beyond the remit of the present study; referring to it aims only to
outline the overall frequency of secondary glass working activities in the region.
distribution networks (within a radius of less than 50 km) and regional networks (within a radius of more than 50 km, and up to 100 – 300 km) as suggested by Morrisson (2012a). As mentioned earlier, a trend of ‘decentralisation’ of secondary glass working towards the end of Late Antiquity in the Eastern Balkans is evident. The
workshops of the late 3rd – 4th c. are mostly situated in urban contexts (e.g. in Serdica, Philippopolis, Novae, Oescus) but during the 5th – 6th c. manufacturing centres emerge in smaller semi-urban fortified settlements as well (e.g. ‘Gradište’ site near Gabrovo; Fig. VI.7.C.; mentioning of glass working in Odartsi – see Section IV.1.1.). However, interpreting this trend simply as a sign of the growing importance of the smallest-scale production and distribution networks would not be accurate. For instance, explaining the economic position of the workshop excavated near Gabrovo as one of only local significance and linked to the local distribution networks within the nearest neighbourhood may not be adequate. The remains of six circular furnaces found there could imply a bigger scale of production, indicating a wider area of spread of the finished products/ satisfying sizable consumption demands. In contrast, a broadly contemporaneous glass working activity in Serdica, ‘MS 8-II’ site, was identified by a substantial amount of debris but no production installation was found (Fig. VI.7.B.; see Section V.2.7.). The alleged workshop is situated within the urban contexts of the provincial capital of Dacia Mediterranea. However, the assemblage indicates mostly the practice of cullet recycling in ranges which could not possibly go far beyond the immediate consumers’ needs of the town and its surroundings.

Taking into account that glass vessel manufacture in general is a specialised craft exceeding the smallest level of household production for economic self-sufficiency, a certain fragmentation of the glass working in the region in the late 5th – 6th c. can be suggested, which, however does not seem to indicate downturn or significant decline. The process of development of numerous ateliers operating to supply their spatial environments of local to semi-regional scale (i.e. going beyond a radius of ca 50 km but probably not reaching spatial ranges of over 100 km) with finished vessels is interlinked with the gradual disappearance of an earlier, more extensive region-wide distribution of certain relatively elaborate groups of glass tableware (see Sections VI.2.3.1. and VI.2.3.2.). Nevertheless, this is not a sign of decline or stark collapse of the regional networks but mostly an aspect of the overall economic and socio-cultural transformation in the Lower Danube.

Within the dynamic social setting and geo-political instability, a specific unification of the consumers’ needs might have been the reason (or one of the reasons)
for amalgamation of the region-wide and local distribution networks of the late 3rd – 5th c. into numerous ‘semi-regional’ geographical spaces of localised but still quite uniform vessel manufacture/consumption in the late 5th – early 7th c. This process was associated with reduction of the economic significance of the traditional urban centres, and very probably, with an abrupt decrease of the inter-regional import of finished vessels. On the other hand, despite the evident simplification of morphology, and decoration and a certain shift in their usage (see Section VI.2.3.2.), the glass vessels continue to play an important role in the everyday life of the provincial communities. Finally, there are no reasons to reject the commercial nature of the distribution within these localised networks towards the end of antiquity, although an overall stagnant economy would imply shrinkage of market-type transactions.

VI.3.2. Local production and distribution of finished vessels

The following paragraphs outline the available information about vessel manufacture at local level, and address the question of its economic significance. As already pointed out, vessel glass blowing is a specialised craft which requires certain skills, empirical knowledge, raw materials selection, etc. It is improbable that such a production would have developed as a side-activity or just necessitated practical response to common household needs, unlike certain other crafts (smithing, carpentry, weaving, etc.). At the same time, the existence of small vessel glass workshops functioning to supply their immediate surroundings, possibly owned and run by itinerant craftsmen who distributed their own production cannot be rejected. In that case, the main problem would be the small chance of recognising their traces in the archaeological record.

VI.3.2.1. Late third – fifth century local-scale vessel manufacture in the Lower Danube region

Glass vessel production in small-scale local workshops most probably existed during the late 3rd – mid 5th c. Eastern Balkans but evidence of it is quite limited. Direct indications coming from workshops or debris dated to the period seem to be related to the higher level of regional manufacture and distribution networks, mostly linked to
developed urban contexts (e.g. furnaces in Serdica and Philippopolis; see Section VI.2.2.2.). No such remains can be certainly associated so far with manufacturing centres of the smallest local level.

Another opportunity to identify the existence of local-scale workshops can come from indirect evidence of finished vessels within site glass assemblages. Such small manufacturing units would have been able to produce a limited volume of unsophisticated items (hence, it is less likely that they would become detectable in the archaeological record). However, when series of fragments from vessels of identical uncomplicated shape and manufacturing details signifying basic craftsmanship are found in particular contexts, this may well denote the narrowest level of local distribution networks. A rare example of such identification comes from a site in North-Eastern Bulgaria. Fragments of cups (Fig. VI.8.), with simple cracked-off rims, irregular base rings with crude tooling marks, central kick and pontil mark form more than one third of a small vessel glass assemblage excavated in a remote area of Scythia Minor (Cholakova 2008). The uniformity of these finds indicates a consistent craft-style which marks the output of a particular workshop. The quite simple and artless manufacturing suggests that it is representative of the modest local-scale secondary glass working, linked to the local level of distribution.

![Fig. VI.8. Fragments of cups, late 3rd – early 4th c., Telerig in North-Eastern Bulgaria (after Cholakova 2008) – a likely example of small scale locally produced and distributed common vessel glass (not analysed).](image)

* The fragments were found in late 3rd – early 4th c. contexts of a traditional pre-Christian religious centre of local significance near the village of Telerig (Torbatov 2005). The glass is transparent, nearly colourless with light yellow tint and strong surface corrosion; the finds were not available for sampling and analysis within the present project.
Unfortunately, not much can be stated for now about the chemical composition of the glass in circulation at these levels of provincial economy in the late 3rd – 4th c. It would be reasonable to expect that mixed antimony-manganese glass was used for vessel manufacture at that time (e.g. sample G 67, see Section VI.2.3.1.) but so far this suggestion has not been supported by quantitatively reliable evidence.

The same uncertainty regarding the smallest scale workshops concerns the 5th c. contexts as well. Again, the main problem is the difficulty to confidently identify any direct traces of production, or to find indirect clues about the local-level distribution networks. A particular hint may be seen in a small group of fragments from the Dichin glass assemblage (see Section III.2.4.), dated to the first phase of the first period of the site (AD 410-470), and all made of Mn-decolourised glass (=Série 3.2. of Foy et al. 2003). The rim of a cup similar to Isings 96a (G 43 & G 44) is shaped by simple cracking-off with only traces of additional smoothing. The application of such basic technology could be related to production in a small-scale local workshop. At the same time, it may be considered as typical of the HIMT vessel production (cf. G 12; see Section III.2.3.) and the fragments might indicate that Mn-decoloured raw glass supplies occasionally reached an atelier following the ‘HIMT craft-style’, possibly at the local level of distribution.

The same Mn-decolourised raw glass type is used for bowls with fire-rounded rims which have no elaborate blue tread decoration but very sparsely abraded simple lines or ornament (G 45-48). They could tentatively be recognised as another example of items manufactured and acquired within the closer vicinity. Interestingly, all these fragments from Dichin show no signs of intense glass re-use/ recycling, and the fire-rounded rim fragments possibly form one-off procurement to the site*. Acknowledging the uncertainty of the present interpretation, these data can be indicative of limited-scale (occasional?) distribution networks of local level in the 5th c. Lower Danube. The fact that all vessels are made of Mn-decolourised glass confirms the observation that at the time this primary composition dominated the overall circulation.

* Close similarities in their chemical composition indicate that they probably come from a single production episode but it is quite problematic to determine whether the fragments come from a single vessel, or from a few vessels produced from a single batch of glass (see Section III.2.4.).
VI.3.2.2. Sixth century local-scale vessel manufacture in the Lower Danube region: the interpretation of the 6th c. glass composition in the context of distribution networks

The present research suggests that considerable transformations in glass vessel manufacture and distribution took place towards the end of Late Antiquity in the Eastern Balkans. Various political, economic, and socio-cultural factors affected the local-scale secondary glass working in the 6th c. Being nearly ‘invisible’ in the previous centuries, this level of production and distribution had a quite changed position during the 6th c. It became a significant part of the overall provincial industry exceeding the strictly local spatial and economic scale and developing into a set of interlinked ‘semi-regional’ networks (see Sections VI.2.3.2. and VI.3.1.).

Nearly all glass finds from 6th – early 7th c. contexts at Dichin, Odartsi, and Serdica belong to this level of production (in total 79 samples, out of 199 in the project; summarised as functional categories in Section VI.2.3.2.), all manufactured with the 6th c. glass composition (=Série 2.1. of Foy et al. 2003). Interpretation of these glasses in the context of distribution networks is important for a better understanding of the processes at the end of Late Antiquity in the region and certain key points are outlined in the following paragraphs.

As pointed out earlier, evidence of recycling in the 6th c. glasses is well confirmed (Fig. VI.4.; see Section IV.2.2.), indicating a probable intense re-use of the available resources, presumably as a necessary response to the reduced supply of fresh glass. No examples of ‘pristine’ and not adulterated 6th c. glass composition (i.e. original makeup at the stage of primary glassmaking) are known. It is believed that the contamination and mixing of different glasses took place during the re-melting in the secondary glass workshops within the region. The 6th c. glass demonstrates low but yet increased levels of antimony oxide (Sb$_2$O$_3$ ca 50 – 800 ppm) and this compositional change marks an important introduction of a different modus operandi, possibly at the level of local/semi-regional glass working.

The presence of Sb$_2$O$_3$ in concentrations higher than 1000 ppm in the late 3rd – 4th c. is due to the re-melting of Sb-decolourised cullet (see Section VI.2.2.2.), and
Elevated and correlated concentrations of copper, lead, and cobalt oxides as evidence of contamination in the 6th c. glass composition (all the samples plotted) compared to the ‘cleaner’ makeup of the 5th c. Mn-decolourised glass (samples from Dichin vessels and Serdica chunks plotted). However, it is unlikely to explain the traces of antimony oxide in the 6th c. glasses simply as re-use of decolourised fragments since no such primary material was available anymore at that time. The disappearance of Sb-decolourised cullet is already evident in the 5th c. Mn-decolourised glass which is virtually missing any traces of Sb$_2$O$_3$ (see Section III.2.4.). Such a sudden re-appearance of this contamination towards the end of Late Antiquity is most probably an effect of re-melting Roman mosaic tesserae which are commonly opacified with antimony (Henderson 1995; see Section IV.2.2.).
The data from Fig. V.9. plotted as a large-scale scatter-graph and juxtaposed with the intentionally coloured cobalt-blue 6th c. samples from Odartsi and Serdica. The group of Co-blue glasses aligns broadly in the same directions of correlation as observed in trace levels of the non-coloured samples. This suggests that relatively small amounts of the contemporaneous cobalt-blue vessels cullet might be a likely source of contamination in the 6th c. glass.

Recycled mosaic glass in the 6th c. composition would affect the levels of metal oxides used for colouring, even if only at trace concentrations. No particular link of any of them to antimony oxide is observed though, probably because of the indiscriminate addition and (repeated?) mixing of all various colours of available tesserae (Fig. IV.12.A.). At the same time, quite clear correlations of cobalt, copper, lead, and to a certain extent nickel and arsenic suggest another source of contamination (Fig. VI.9.A., B.). It is unlikely that these levels indicate natural impurities in the glassmaking sands.
used for the production of the 6th c. composition, even though such a hypothesis cannot be completely ruled out. However, these metals are often found in varying geological associations in cobalt-bearing deposits, and therefore appear in trace concentrations in glasses coloured with cobalt (Gratuze 2013b, Table 5.1.4.). Cobalt-blue glasses are not too abundant in the 6th c. contexts but some well-dated examples are known. Three stemmed goblets and a chunk of unworked glass in the present dataset are cobalt-blue and contain only insignificant levels of antimony oxide but relatively high amounts of lead and copper (see Section IV.2.3.). When these samples of intentionally coloured glass are plotted together with the 6th c. composition group their levels of Co, Cu and Pb broadly fit the lines of impurity correlations seen in the latter samples (Fig. VI.10.A., B.). Therefore, a probable source of the elevated concentrations of these metals can be identified as cobalt-blue cullet of the contemporaneous late antique composition added in small quantities to the melts of the 6th c. composition. Since no fashion for decorating mass-produced vessels with details of blue glass existed anymore at that time, the re-use of fragments of plain cobalt-blue vessels (e.g. stemmed goblets) is more plausible.

This evidence strongly indicates a working practice of re-melting mixed batches of various available raw materials (different colours of cullet, most probably fresh unworked glass, and mosaic tesserae) which is not recognised through any of the earlier compositional groups in the present dataset. Addition of cullet (traceable due to Sb-opacified mosaic glass) seems probable even at the stage of primary making of the 6th c. glass (see Section IV.2.2.). However, there are no firm arguments to exclude such a possibility at the stage of the local secondary glass working as well. The implications of this 6th c. phenomenon may easily be defined as technological ‘decline’. However, considered from the point of view of distributional networks, this indiscriminate recycling suggests mostly a necessity of a reasonable utilisation and maximised maintenance of the locally available reservoir of glass, in a situation of reduced inter-regional supplies (both of fresh glass and finished vessels). At the same time, the possibility to distinguish clear elemental correlations of the contaminants indicates that ‘indiscriminate’ recycling was not too extensive, or entirely random/
unrestricted, and still certain choices have been made to keep an acceptable level of quality and appearance of the glass.

However, the most important aspect of this practice concerns the ways of procurement of raw materials. Regular and organised overseas supplies of fresh glass certainly still existed (even if reduced) but a considerable part of the raw materials must have been locally collected. As mentioned earlier, a decline of the urban centres in the Eastern Balkans is one of the characteristics of that time, and it inevitably lead to an abandonment of urban public buildings from the Roman period. Mosaics might be an expected as part of their decoration, and scavenged tesserae from there must have been a suitable/ easily accessible source of glass for recycling. In this way, the general outline of the raw materials procurement for the 6th c. workshops in the Lower Danube suggests a rather adaptive and resourceful practice of complementing the reduced volume of fresh glass, but also shows a certain disintegration of the region-wide networks of higher levels of organisation. This is one of the clues for identifying the increased significance of the local-scale networks which became the only economic alternative in the situation of limited inter-regional distribution and fragmented region-wide links.

Some other characteristics of the present dataset should be also taken into account when discussing the growth of the local-level glass vessel manufacture and distribution during the 6th – early 7th c. in the studied region. The considerable number of finds dated to that time signifies considerable consumers’ needs and usage of vessel glass, even though a certain technological ‘decline’ (simplification?) in the secondary glass working is noticeable. The general unification of the chemical glass composition in use (i.e. the 6th c. glass composition) and the nearly identical manufacturing details and morpho-typology of the vessels point to remarkable similarities in the context of economic fragmentation, most probably linked to a culturally determined equalising of usage. At the same time, particular intricate details of vessel distribution (for example, various types of hanging oil lamps) imply that the networks of their spread can be

---

*A short note about a late antique glass furnace excavated in the ruins of the abandoned Roman public bath in Odessus (Minčev 1988, 50) is an indirect hint for such a simple way of acquiring raw materials.*
described as ‘semi-regional’, with size ranging between narrow local and broader regional ranges.

Therefore, a complete reconstruction of the processes would not necessarily suggest that the generally stagnant and fragmented economy of the 6th c. in the region resulted mostly in rudimentary local vessel glass production and distribution on the smallest scale. Instead, various aspects of the economic, political, and socio-cultural development in the Eastern Balkans signify the emergence at a ‘semi-regional’ level of numerous vessel glass manufacturing centres, smaller than earlier region-wide oriented glass ateliers, but at the same time with a broader economic significance than strictly local vessel glass manufacture. These workshops and their respective networks of raw materials supplies and finished product distribution actively operated as one of the important components of a transformed 6th c. provincial economy at the margins of the Empire.

The Sections of Chapter VI outline the interpretation of the various glass groups in the present dataset, defined in terms of vessel manufacturing characteristics and morpho-typology, and chemical composition. Their significance is discussed here in the framework of distribution as a complex multileveled economic and socio-cultural phenomenon rather than simply a spatial movement of various materials. The dynamics of the inter-regional imports to the Lower Danube region indicate a range of underlying mechanisms – from commercial diversified trade with raw glass and/or finished vessels, to monopolised supplies as an effect of political factors, spread of items as personal possessions and/or symbols of social hierarchies. The region-wide networks of vessel glass manufacture and distribution seem more active during the 4th – 5th c. AD when different craft traditions can be recognised. A major shift in the raw materials procurement and vessel manufacture during the 6th – early 7th c. AD lead to an increased importance of the local-scale networks and their growth into quite unified and interlinked but still somewhat varying ‘semi-regional’ segments of a transformed and decentralised provincial economy.
The final Chapter VII delineates the main points of the present study, and summarises the conclusions regarding the networks of distribution of late antique vessel glass in the Lower Danube region. Furthermore, an attempt is made to outline the overall character of the dynamics of distribution networks in terms of their different spatial levels and socio-economic mechanisms of functioning. Perspectives for future development of the research are also touched upon.
The main objective of the present research, as defined in the beginning of the thesis, was to characterise the distribution of vessel glass in the Lower Danube region in the late 3rd – early 7th c. through an integration of conventional artefact study and scientific analysis. The explanatory model of distribution networks was developed in order to reveal an interpretative account (as opposed to a mere description of static schemes of production – supply – consumption), and to achieve a certain understanding about the socio-economic phenomena reflected through the patterns of late antique glass vessel manufacture, circulation and usage.

Three site assemblages, namely Dichin Odartsi and Serdica, consisting predominantly of vessel fragments and to a lesser extent of production debris and window panes were studied and the finds were recognised by their artefact characteristics, context, date, chemical composition, origin, etc. The starting research question, or task, of the project concerned the way in which these materials, i.e. the dataset of primary evidence, should be approached in order to accomplish their meaningful and interpretable grouping. The appropriate methodology which addressed this question was based on the well-established technological style/chaine opératoire approach. Accordingly, an integrated classification of groups was outlined, taking as leading criteria both the technologies of glass making (in terms of primary melting and subsequent compositional modifications) and the technologies of vessel manufacture and finishing. Such complex and even versatile criteria enabled to formulate the groups in the present study as an open and flexible construct, which was seen not as a final aim of the research but as a tool for addressing its further questions.

Several main groups were identified in the studied assemblages. Bowls with cracked-off and polished rims, decorated using fine wheel-engraving were made of glass of Levantine I composition (naturally coloured and Mn-decolourised). Several unworked chunks of raw glass of the same chemical makeup indicated that the
production of the Syro-Palestine glass centres was supplied to the Lower Danube region both as finished objects and as raw material for the secondary workshops. A similar craft style of cracked-off outsplayed rims but most often left unworked and with considerably more crude manufacture characterised the vessels made of HIMT glass composition. The tall beakers and cups in this group were occasionally decorated with thin wheel-engraved horizontal lines and applied blobs of dark blue glass. These vessels were tentatively interpreted as production of the secondary workshops within the Lower Danube region, while some other vessel shapes made of the same HIMT glass could have been imported as finished objects. Another, much smaller group was formed of vessels with elaborate engraved and cut figured decoration produced of Sb-decolourised glass. These exceptional items certainly originated from a higher level of the late Roman vessel glass industry, and represent luxurious imports to the studied region. At regional level, a technology of likely recycling of various kinds of cullet resulted in mixed Sb–Mn composition which possibly was used in regional and local small scale secondary workshops for unsophisticated vessel and window pane production. One of the major groups in the present dataset was formed of vessel fragments and a few unworked chunks of 5th c. Mn-decolourised glass composition. The variety of shapes and manufacturing techniques in this group reflected the diversity of the glassblowing ateliers which were supplied with this primary glass. Examples of skilfully decorated vessels with abraded ornaments were possibly brought from far afield to their context of usage in the Balkans, but the larger part represented the production of the regional manufacturing centres, as well as possibly that of the smaller local workshop. A particular technological style of fire-rounded rims and blue trailed decoration (on bowls, beakers, oil lamps, etc.) was interpreted as characteristic of the secondary glass working in the studied region. A similar application of pontil technique but of very good level of craftsmanship denoted a group of undecorated beakers and cups made of HIT glass composition with saturated green colour. This group was linked to the distribution of finished vessels to the Lower Danube because of its quantitatively limited presence and the absence of close parallels in the region. The most abundant group in the studied assemblages was formed of stemmed goblets, oil lamps, and a few cases of different vessel shapes, window pane pieces and unworked chunks of 6th c. composition, with its iron-rich sub-group. All the fragments
in this group illustrated a rather standardised pontil technique, quite occasional optic blowing, fire-rounded rims and generally no use of additional decoration. A trend of
less attentive workmanship (i.e. visible tooling marks and manufacturing flaws), as well as its overwhelming quantitative prevalence implied that this group marked the production of the local and ‘semi-regional’ secondary workshops of smaller or more substantial scale in the Lower Danube. Finally, several exceptional vessels suggested that certain other less popular groups (mixed flux glass; Co-blue glass) have occasionally reached the region as finished vessels (stemmed goblets) and/ or probably as raw material.

As evident from this summarised overview of the groups in the present integrated classification, their definitions were not simply related to the geochemical characteristics of the glass compositions (even though this aspect was certainly taken into account) and the patterning of different craft styles was one of the key criteria of classification. The reasoning of this approach came from the necessity to attain an agreement between the principles of classification applied to the primary dataset and the principles of its interpretation, in order to discuss the next research question of the present study. It addressed the problem of recognition of various levels and types of distribution networks within the outlined grouping, in terms of their spatial scale (inter-regional, regional, and local) and socio-economic mechanisms of functioning (market-type trade, commercialised tied exchange, non-commercial distribution). An intricate set of arguments and questions, which not always had definite and unambiguous answers were articulated already at the stage of initial classification. A combined interpretation of archaeological and archaeometric evidence allowed to establish a tentative evaluation of vessels produced within the region, or brought from far afield as finished objects, items for everyday use and glassware with special significance, cheap and expensive, mass-produced and luxurious, etc.

Based on these implications, a schematic outline of the groups according to their associations to different levels of distribution networks is presented in Fig. VII.1., acknowledging the absence of evidence in certain sections. Moreover, the opportunity to study well-dated finds enabled to situate these conclusions within a defined chronological framework. The late Roman period (the late 3rd – 4th c.) remained relatively underrepresented in the studied dataset due to the specifics of the site assemblages. Nevertheless, luxurious engraved vessels made of Sb-decolourised glass
were distributed to the Balkans as inter-regional commercial imports, or quite possibly – as gifts and symbols of social status, i.e. as long-distance non-commercial distribution of goods. Wheel-cut bowls made of Mn-decolourised Levantine I glass likely represented inter-regional trade from the Syro-Palestine region at that time. The character of the supplies of primary unworked glass to the Lower Danube region in the late 3rd – 4th c. could not be identified due to insufficient primary evidence. At the same time, the contemporaneous examples of mixed Sb–Mn composition were identified as recycled glass in commercial circulation at the level of regional networks, which also probably served the smallest scale local networks of vessel glass manufacture and distribution.

In the end of the 4th – early 5th c. the HIMT glass composition was introduced to the region. Occasional examples of finished vessels could have been imported as single non-commercial movement, or possibly as limited inter-regional trade distribution. However, the bigger part of the HIMT fragments (beakers and bowls with cracked-off rims) were identified as being manufactured and traded as common glassware within the Eastern Balkans, mostly due to their not too high quality and widespread presence. Accordingly, the HIMT primary glass must have been also part of the inter-regional trade supplies of raw materials for the regional workshops during the 5th c., and more actively in its first half. Following the commonly accepted understanding about the origin of HIMT glass composition, Egypt/ Northern Sinai were assumed as the primary starting point of this inter-regional distribution network to the Lower Danube.

At the same time, the present dataset indicated that the main glass group of that time was formed of 5th c. Mn-decolourised composition. Sporadic or more regular inter-regional import of finished vessels of this primary glass manufactured outside the Lower Danube looked possible, with an example of likely non-commercial one-off procurement. Nevertheless, the majority of the materials suggested that the Eastern Balkan workshops of the 5th c. must have been supplied predominantly with Mn-decolourised primary glass, as confirmed by the unworked chunks. A range of vessels (blue trail decorated) had a region-wide distribution, while the smallest level of local networks could also be supplied with the same glass composition used to produce simple vessel shapes. The diversity of groups attested in the 5th c. was further
complemented by the long-distance commercial (or partly non-commercial) import of wheel-engraved bowls made of Levantine I glass, presumably from Syro-Palestine. A small group of plain vessels made of HIT glass suggested that inter-regional networks of finished objects could have had the meaning of occasional non-economic distribution. Finally, the long-distance commercial distribution of Levantine I primary glass was also attested but obviously the quantities of these imports were not too abundant, and the glass was incorporated in the mixed batches of the secondary workshops.

Remarkably, by the early 6th c. this variety of vessel glass groups and networks of their production and distribution came to an end. Evidence of inter-regional movement of finished vessels – as commercial activities or as non-commercial phenomenon – were quite scarce, and possibly consisted of a few examples of stemmed goblets made of Co-blue glass and glass produced with mixed flux generally dated to the 6th – early 7th c. At the same time, the supplies of unworked primary glass were probably reduced but they did not cease. On the contrary, the long-distance distribution of 6th c. glass composition dominated the region, probably as monopolised tied commerce, and provided raw material for the secondary workshops in the Eastern Balkans. The limited presence of Levantine I primary glass cannot be excluded but the available finds were insufficient to demonstrate its steady spread in the region. The workshops within in the region produced a limited range of objects used mostly as lighting devices, and were applying rather standardised techniques of manufacture and finishing. The patterns of distribution suggested that the region-wide networks of the 5th c. were not active during the 6th – early 7th c. but a certain fragmentation of the overall provincial economy resulted in increased significance of the local-scale production and circulation of vessel glass. Therefore, the definition of ‘semi-regional’ networks was introduced in order to denote this change.

This outline of the distribution networks revealed that they were certainly more than just technical routes for physical movement of products, and their developments and functions reflected complex socio-economic processes and transformations at the margins of the Empire. Therefore, addressing the final question of the present study – to what extent is it plausible to relate the identified networks to
known historical phenomena of the period – opened quite intriguing perspectives of the research. In general, as expected for the developed economy of Late Antiquity, the distribution of glass as raw material and finished vessels was apparently driven mostly by trade and commercial factors. However, certain non-commercial networks also existed, and could be linked to the representative character of luxurious and decorated glassware as gift, symbols of social status and links, patronage relations, etc. The cage-cups were probably the most telling example of such non-utilitarian role of vessel glass while other less expensive items could have served the same functions but on lower societal levels. The indications of non-commercial distribution in the Lower Danube region could be associated with the complex social phenomena due to the presence of various ethnic groups in this borderline area of the Empire. The regionally manufactured and distributed vessels of HIMT glass could also be tentatively related to this intricate pattern of identities since these glasses had a distinct craft style and remained somehow detached from the general development of e secondary glass industry in the Lower Danube.

Finally, the significant shift in the primary glass composition distributed to the Eastern Balkans was interpreted as likely evidence for a monopolised ‘pick-a-back’ commercial supply tied to the state led distribution networks of the *quaestura exercitus* – an institution subordinated directly to the central government and possibly responsible for the provision of staple food for the threatened Danubian *limes* in Moesia Inferior and Scythia Minor.

From a more general viewpoint, the discussed change in vessel glass production and usage in the 6th c. – early 7th c. compared to the earlier traditions coincided with a wide range of socio-cultural and economic and ethnic transformations in the region. Regarding vessel glass, a certain downfall of the earlier patterns of distribution and usage became evident but the new phenomenon of the ‘semi-regional’ networks apparently took their place. The visual representative aspect of glass as material (e.g. decolourised compositions) and as finished vessels (e.g. decorated vessels used as tableware) lost its meaning and the functional practical aspect received predominant attention – both in glass production (e.g. increased recycling, variable
glass tints) and as meaning of the vessels (e.g. lighting devices which allow brighter illumination).

Summarising a brief outlook for future research in the directions outlined in this thesis, it has to be remembered that the initial points of the distribution networks, i.e. the locations of primary glass production of certain groups attested in the studied assemblages, are still not well-defined. Provenancing the 5th c. Mn-decolourised composition and 6th c. composition would be of particular importance for the Lower Danube region, since a better understanding of their geographical origin would probably shed light on the mechanisms of functioning of these inter-regional networks. More analytical and archaeological evidence would also help to improve the interpretation of the peculiar group of HIMT vessels with cracked-off rims which were quite popular during the 5th c. in various regions of the Empire and beyond. The application of more advanced statistical methods remains as an opportunity for a more complete incorporation of the entire analytical set of compositional data in a multidisciplinary study. Last but not least, the validity of the integrated classification approach suggested in the present thesis needs to be corroborated on the basis of different vessel glass assemblages.

The narrative of distribution networks at the margins of the Empire constructed in this research will be certainly complemented, refined, and possibly modified or proved unreliable by future research. And yet, this is an attempt to go beyond the static descriptions in archaeology and archaeometry and to approach the fragmented material remains of past phenomena in an interpretative way. After all, as admitted quite reasonably, archaeological knowledge is something that is made rather than just assembled, and it does not consist of ‘discovering’ the facts but of ‘crafting’ the facts (Shanks and McGuire 1996, 78-79).
BIBLIOGRAPHY


Cholakova, A., 2014. Networks of distribution at the margins of the Empire – late antique glass vessels from the Lower Danube region. In Kassianidou, V., and

351


Giliozzo, E., Turchiano, M., Giannetti, F. and Santagostino Barbone, A., 2015b. Late antique glass vessels and production indicators from the town of Herdonia


ICP-MS documents (Hacettepe University ICP-MS Laboratory) http://www.icp.hacettepe.edu.tr/belgeler.shtml (accessed July 2014).


Ivanov, M., 2013. Fragment of a second *vas diatretum* from Serdica. *Archaeology* (Sofia) 54(1), 107-113 (in Bulgarian).


**Torbatov, S., 2002a.** *Coin Circulation in the Hill-Top Settlement near Odartsi (310 BC – AD 610).* Veliko Tarnovo: Faber (in Bulgarian).

**Torbatov, S., 2002b.** *The Defence System of the Late Roman Province of Scythia (the End of the 3rd – the 7th c. A.D.).* Faber: Veliko Tarnovo (in Bulgarian).


**The Transition to Late Antiquity.**


**Vachkova, V., 2013.** Why Constantine the Great used to say, ‘Serdica is my Rome’? *Bulgarian Historical Review* 41(1/2), 3-16 (in Bulgarian).


Appendix A.1.

Appendix A.1.
Appendix A.2.

Distribution of vessel shapes and groups of manufacturing techniques juxtaposed with the main chemical glass compositions of the 5th and 6th c. and their respective sub-groups. Two samples-outliers, both coming from blue trail decorated vessels, of the 5th c. Mn-decolourised composition are added to the total number of the main group but were not counted among the identifiable vessels since it is uncertain whether they, in terms of their chemical makeup, actually belong to the main group or to the intermediate sub-group of the 5th c. Mn-decolourised glass.
### Appendix A.2.

<table>
<thead>
<tr>
<th>Manufacturing Techniques</th>
<th>Vessel Shapes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cracked-off rim</td>
<td>? Lamp base</td>
</tr>
<tr>
<td>Traced decoration in relief</td>
<td>Steamed gablets</td>
</tr>
<tr>
<td>Abraded decoration or self-coloured glass</td>
<td>Lamp with pointed base</td>
</tr>
<tr>
<td>Plain walls:</td>
<td>Lamps 11, 13, 14, see ODR 54</td>
</tr>
<tr>
<td>Fire-rounded thickened rim</td>
<td></td>
</tr>
<tr>
<td>Marvered/semi-marvered blue glass</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>24 identifiable vessels (out of 32 samples)</td>
<td>44 identifiable vessels (out of 50 samples)</td>
</tr>
<tr>
<td>Iron-rich sub-group</td>
<td>Iron-rich sub-group</td>
</tr>
<tr>
<td>27 identifiable vessels (out of 29 samples)</td>
<td>27 identifiable vessels (out of 29 samples)</td>
</tr>
<tr>
<td>Main group</td>
<td>Main group</td>
</tr>
<tr>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Intermedia sub-group</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>2</td>
</tr>
<tr>
<td>Sub-group</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>3</td>
</tr>
<tr>
<td>Vessels</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>3</td>
</tr>
<tr>
<td>Vessels</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>Vessels</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>Vessels</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>Vessels</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>Vessels</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>Vessels</td>
<td></td>
</tr>
</tbody>
</table>
Appendix A.3.

Scatter graph of the trace oxide ratios of the main glass compositions identified in the present dataset. Note the distances between the cluster of 5\textsuperscript{th} c. Mn-decolourised glass and 6\textsuperscript{th} c. composition and the clusters of HIMT and HIT samples, and Levantine I samples.
Appendix A.4.

Scatter graph of strontium oxide vs lime of the main glass compositions identified in the present dataset. Note the position of the sample ODR 35 with the lowest SrO concentration.
Appendix A.4.
Appendix A.5.

Scatter graph of potash vs magnesia of the main glass compositions identified in the present dataset. Note the position of Levantine I samples from Dichin with elevated potash, and samples SER 42 and SER 44 possibly produced with mixed flux.
Appendix A.5.
Appendix A.6.

Calculations of two theoretical schematic reconstructions of the Co-bearing colourant used in the cage-cup from Serdica (samples SER 26 and SER 27) and for its closest analogy, the CMG *patera* fragment (see Section IV.3.3.3.). The formulae used for each of the oxides when the composition of the colorant is modelled are: \(((\text{blue glass value} \times 10) - (\text{base colourless glass value} \times 9))/1; (\text{blue glass value} \times 10) - (\text{base colourless glass value} \times 5))/5. The compositional data of CMG *patera* from Brill *et al.* 1999-2012; no result for CoO is reported there so a theoretical value of 400 ppm is entered in the table to allow the modeling.
### Appendix A.6.

<table>
<thead>
<tr>
<th></th>
<th>base glass</th>
<th>coloured glass</th>
<th>modelling the composition of the colorant</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>SER 26 CMG <em>patera</em></td>
<td>SER 27 CMG <em>patera</em></td>
<td>Serdica CMG <em>patera</em></td>
</tr>
<tr>
<td><strong>wt%</strong></td>
<td></td>
<td></td>
<td>if recipe is 9:1*</td>
</tr>
<tr>
<td>SiO₂</td>
<td>66.9</td>
<td>66.00</td>
<td>57.9</td>
</tr>
<tr>
<td></td>
<td>69.4</td>
<td>68.3</td>
<td>58.4</td>
</tr>
<tr>
<td>Na₂O</td>
<td>20.2</td>
<td>19.30</td>
<td>11.2</td>
</tr>
<tr>
<td></td>
<td>17.4</td>
<td>16.6</td>
<td>9.4</td>
</tr>
<tr>
<td>Al₂O₃</td>
<td>2.23</td>
<td>2.33</td>
<td>3.23</td>
</tr>
<tr>
<td></td>
<td>2.29</td>
<td>2.37</td>
<td>3.09</td>
</tr>
<tr>
<td>CaO</td>
<td>6.70</td>
<td>6.72</td>
<td>6.9</td>
</tr>
<tr>
<td></td>
<td>7.53</td>
<td>7.22</td>
<td>4.43</td>
</tr>
<tr>
<td>K₂O</td>
<td>0.31</td>
<td>0.52</td>
<td>2.41</td>
</tr>
<tr>
<td></td>
<td>0.62</td>
<td>0.66</td>
<td>1.02</td>
</tr>
<tr>
<td>MgO</td>
<td>0.77</td>
<td>0.62</td>
<td><strong>-0.73</strong></td>
</tr>
<tr>
<td></td>
<td>0.78</td>
<td>0.67</td>
<td><strong>-0.32</strong></td>
</tr>
<tr>
<td>Fe₂O₃</td>
<td>0.84</td>
<td>1.04</td>
<td>4.64</td>
</tr>
<tr>
<td></td>
<td>0.54</td>
<td>1.00</td>
<td>5.14</td>
</tr>
<tr>
<td>P₂O₅</td>
<td>0.05</td>
<td>0.10</td>
<td>0.58</td>
</tr>
<tr>
<td>Cl</td>
<td>1.14</td>
<td>1.21</td>
<td>1.84</td>
</tr>
<tr>
<td>TiO₂</td>
<td>0.11</td>
<td>0.09</td>
<td><strong>-0.08</strong></td>
</tr>
<tr>
<td></td>
<td>0.10</td>
<td>0.07</td>
<td><strong>-0.173</strong></td>
</tr>
<tr>
<td>MnO</td>
<td>0.16</td>
<td>0.27</td>
<td>1.22</td>
</tr>
<tr>
<td></td>
<td>0.03</td>
<td>0.29</td>
<td>2.666</td>
</tr>
<tr>
<td>Sb₂O₃</td>
<td>0.60</td>
<td>1.31</td>
<td>7.65</td>
</tr>
<tr>
<td></td>
<td>0.65</td>
<td>1.52</td>
<td>9.35</td>
</tr>
<tr>
<td><strong>totals:</strong></td>
<td>99.81</td>
<td>99.51</td>
<td>96.76</td>
</tr>
<tr>
<td></td>
<td>99.33</td>
<td>98.70</td>
<td>93.00</td>
</tr>
<tr>
<td><strong>ppm</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CoO</td>
<td>4</td>
<td>380</td>
<td>3,764</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>400</td>
<td>3,973</td>
</tr>
<tr>
<td>CuO</td>
<td>43</td>
<td>1,247</td>
<td>12,083</td>
</tr>
<tr>
<td></td>
<td>14</td>
<td>1,200</td>
<td>11,874</td>
</tr>
<tr>
<td>ZnO</td>
<td>52</td>
<td>55</td>
<td>82</td>
</tr>
<tr>
<td>SnO₂</td>
<td>16</td>
<td>111</td>
<td>966</td>
</tr>
<tr>
<td>PbO</td>
<td>74</td>
<td>2,201</td>
<td>2,1344</td>
</tr>
<tr>
<td></td>
<td>30</td>
<td>1,800</td>
<td>17,730</td>
</tr>
<tr>
<td><strong>totals:</strong></td>
<td>189</td>
<td>3,994</td>
<td>33,577</td>
</tr>
<tr>
<td></td>
<td>73</td>
<td>3,400</td>
<td>67,53</td>
</tr>
</tbody>
</table>

*colorant=10% of the final batch
*colorant=50% of the final batch
Appendix A.7.

Summary of the data quality assessment for each analytical run of EPMA and LA-ICP-MS measurements with indications of the decisions made for particular results; the comments are only on the problematic issues with stronger interpretive significance, SiO$_2$ is not included.
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Na₂O</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Al₂O₃</td>
<td>corrected if used</td>
<td>corrected and fully used</td>
<td>corrected and fully used</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>K₂O</td>
<td>dubious</td>
<td>partly used</td>
<td>partly corrected</td>
<td>partly corrected</td>
<td>partly corrected</td>
<td>partly corrected</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CaO</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>MgO</td>
<td>partly used</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>TiO₂</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>P₂O₅</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>MnO</td>
<td>partly corrected</td>
<td>partly ignored</td>
<td>partly corrected</td>
<td>partly ignored</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sb₂O₃</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cl₂O₅</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>MgO</td>
<td>partly used</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SrO</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>‘traces’ incl. SrO</td>
<td>ignored</td>
<td>ignored</td>
<td>ignored</td>
<td>ignored</td>
<td>ignored</td>
<td>ignored</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Appendix A.8.

Addenda to Chapter V

The summarised review in Appendix A.8. is aimed at complementing the archaeological background of the sites which provided samples for the present project. The main glass assemblages from Dichin, Odartsi, and Serdica were extensively discussed in Chapters III, IV and V, including overviews of the sites’ histories, chronologies and archaeological characteristics. Two more samples from two other sites were also joined to the analysed dataset in order to achieve a better representation of some particular glass groups.

A cup fragment made of HIMT glass (sample G 4, see Section V.2.2.; Fig. V.8.) was found at a hill-top fortified settlement near present-day Samokov, region of Sofia. The site is situated at the steep Northern skirts of Rila Mountain in a remote provincial area away from the main transport and communication networks in antiquity (Fig. V.1.). This settlement has two phases of habitation during Late Antiquity: the 4\textsuperscript{th} – early 5\textsuperscript{th} c. and the 6\textsuperscript{th} c.; the analysed fragment was found in a domestic context from the first phase. The excavations near Samikov revealed that the special occupation of the inhabitants of the site – industrial scale iron smithing – was the main reason for its establishment at this spot, in a region famous for its iron ore deposits (Cholakova and Hadjiangelov 2010). The site has generally poorer characteristics of constructions, internal planning, and small finds ranges compared to Dichin and Odartsi. A surprisingly small number of glass vessel fragments were found there, suggesting that the population of the Samokov site was not steadily included in the main networks of distribution at the regional level but most probably was only occasionally supplied or was bound to the smaller scale local networks.

An unworked chunk of glass of mixed Sb- and Mn-decolourised composition (sample PLD 1, see Section V.2.6.) comes from the filling of a tank furnace excavated in Philippopolis, present-day Plovdiv in Southern Bulgaria (see Appendix A.1.). Philippopolis is one of the most important towns in Hellenistic and Roman Thrace,
which remained provincial capital during Late Antiquity as well. It is situated on the main ancient road in the Balkans (*Via Diagonalis* also known as *Via Militaris*) and was a well-connected and prosperous centre of trade and a various craft productions. The wealth of the town and its citizens is attested by the imposing public and private architecture, streets, religious buildings, etc. (Ivanov and Bülow 2008), even though Philippopolis followed the overall trend of urban decline towards the end of Late Antiquity. The tank furnace was excavated within the space of a large private building decorated with mosaic floors, and could be tentatively linked to the construction of the building in the late 3rd–early 4th c. (Cherneva 2014). Presumably, a sizable amount of architectural glass must have been needed for such an elite private domestic complex. Accordingly, the presence of the glass furnace there is not unexpected, and it resembles the position of the Serdica furnace in the centre of the town, unrelated to other craft productions (see Section V.2.6.).

A large piece of clean light blue-greenish glass excavated within the furnace remains was sampled and analysed, and this data complements in a very appropriate way the results obtained from the analyses of the Serdica furnace chunks. In a more general perspective, the glass from Philippopolis is far too abundant, representing nearly all the manufacturing groups known from the archaeological research on Roman and late antique glass vessels, in contrast to assemblages from sites like Samokov. Therefore, only a single sample from a particular production context from Philippopolis is included in the present project, in line with the targeted sampling approach, and no other finds from this town were analysed since their comprehensive study stays beyond the scope of this research.
<table>
<thead>
<tr>
<th>Week</th>
<th>10 AM</th>
<th>2 PM</th>
<th>4 PM</th>
<th>6 PM</th>
<th>8 PM</th>
<th>10 PM</th>
<th>Midnight</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>43.5</td>
<td>42.2</td>
<td>41.8</td>
<td>41.5</td>
<td>41.2</td>
<td>40.9</td>
<td>40.6</td>
</tr>
<tr>
<td>2</td>
<td>42.1</td>
<td>41.8</td>
<td>41.5</td>
<td>41.2</td>
<td>40.9</td>
<td>40.6</td>
<td>40.3</td>
</tr>
<tr>
<td>3</td>
<td>40.9</td>
<td>40.6</td>
<td>40.3</td>
<td>40.0</td>
<td>39.7</td>
<td>39.4</td>
<td>39.1</td>
</tr>
<tr>
<td>4</td>
<td>39.6</td>
<td>39.3</td>
<td>39.0</td>
<td>38.7</td>
<td>38.4</td>
<td>38.1</td>
<td>37.8</td>
</tr>
<tr>
<td>5</td>
<td>38.3</td>
<td>38.0</td>
<td>37.7</td>
<td>37.4</td>
<td>37.1</td>
<td>36.8</td>
<td>36.5</td>
</tr>
<tr>
<td>6</td>
<td>37.0</td>
<td>36.7</td>
<td>36.4</td>
<td>36.1</td>
<td>35.8</td>
<td>35.5</td>
<td>35.2</td>
</tr>
<tr>
<td>7</td>
<td>35.7</td>
<td>35.4</td>
<td>35.1</td>
<td>34.8</td>
<td>34.5</td>
<td>34.2</td>
<td>33.9</td>
</tr>
</tbody>
</table>

**APPENDIX B.1.2.**Justification of OPAF and IAC-IQS results for the samples measured by both techniques
<table>
<thead>
<tr>
<th>wt%</th>
<th>ppm/ wt%</th>
<th>TiO2</th>
<th>MnO</th>
<th>ppm values</th>
<th>Fe2O3</th>
<th>TiO2</th>
<th>ZrO2</th>
<th>Cr2O3</th>
<th>HFo2</th>
<th>Nb2O3</th>
<th>Y2O3</th>
<th>La2O3</th>
<th>CeO2</th>
<th>PrO2</th>
<th>Nd2O3</th>
<th>NiO</th>
<th>As2O3</th>
<th>La2O3</th>
<th>CeO2</th>
<th>PrO2</th>
<th>Nd2O3</th>
<th>NiO</th>
<th>As2O3</th>
</tr>
</thead>
<tbody>
<tr>
<td>nat. coloured</td>
<td>G 25</td>
<td>70.4</td>
<td>14.7</td>
<td>2.99</td>
<td>8.76</td>
<td>0.86</td>
<td>0.57</td>
<td>0.35</td>
<td>1484</td>
<td>1.01</td>
<td>0.06</td>
<td>0.04</td>
<td>LA-ICP-MS 2010</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>G 31</td>
<td>70.5</td>
<td>14.9</td>
<td>2.99*</td>
<td>8.90</td>
<td>0.95</td>
<td>0.51</td>
<td>0.33</td>
<td>1205</td>
<td>0.98</td>
<td>0.05</td>
<td>0.03</td>
<td>LA-ICP-MS 2010</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>G 27</td>
<td>70.8</td>
<td>13.9</td>
<td>2.94</td>
<td>8.86</td>
<td>0.95</td>
<td>0.54</td>
<td>0.33</td>
<td>1182</td>
<td>1.55</td>
<td>0.07</td>
<td>0.04</td>
<td>LA-ICP-MS 2010</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>G 26</td>
<td>70.4</td>
<td>14.6</td>
<td>3.10</td>
<td>8.67</td>
<td>0.89</td>
<td>0.53</td>
<td>0.46</td>
<td>1205</td>
<td>0.85</td>
<td>0.06</td>
<td>0.07</td>
<td>LA-ICP-MS 2010</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>G 29</td>
<td>71.1</td>
<td>13.9</td>
<td>3.26</td>
<td>8.55</td>
<td>0.90</td>
<td>0.56</td>
<td>0.47</td>
<td>1286</td>
<td>0.78</td>
<td>0.07</td>
<td>0.14</td>
<td>LA-ICP-MS 2010</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>G 30</td>
<td>70.4</td>
<td>14.1</td>
<td>3.22</td>
<td>8.96</td>
<td>0.85</td>
<td>0.57</td>
<td>0.49</td>
<td>1350</td>
<td>0.93</td>
<td>0.07</td>
<td>0.14</td>
<td>LA-ICP-MS 2010</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>G 32</td>
<td>69.9</td>
<td>14.1</td>
<td>3.42</td>
<td>9.35</td>
<td>0.89</td>
<td>0.57</td>
<td>0.48</td>
<td>1250</td>
<td>0.79</td>
<td>0.08</td>
<td>0.15</td>
<td>LA-ICP-MS 2010</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>SER 1</td>
<td>71.0</td>
<td>16.3</td>
<td>2.81</td>
<td>7.30**</td>
<td>0.56</td>
<td>0.82</td>
<td>0.47</td>
<td>561</td>
<td>1.00</td>
<td>0.09</td>
<td>0.02</td>
<td>LA-ICP-MS 2010</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>SER 3</td>
<td>68.2</td>
<td>17.1</td>
<td>2.86</td>
<td>8.10*</td>
<td>0.68</td>
<td>0.67</td>
<td>0.46</td>
<td>964</td>
<td>1.01</td>
<td>0.08</td>
<td>0.03</td>
<td>LA-ICP-MS 2010</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>SER 6</td>
<td>67.0</td>
<td>14.9</td>
<td>3.28</td>
<td>10.49*</td>
<td>0.75</td>
<td>1.09</td>
<td>0.55</td>
<td>1095</td>
<td>0.88</td>
<td>0.10</td>
<td>0.02</td>
<td>LA-ICP-MS 2010</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>SER 7</td>
<td>68.7</td>
<td>16.4</td>
<td>2.69</td>
<td>8.56*</td>
<td>0.68</td>
<td>0.85</td>
<td>0.54</td>
<td>874</td>
<td>0.79</td>
<td>0.10</td>
<td>0.02</td>
<td>LA-ICP-MS 2010</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mn-decolourised</td>
<td>SER 12</td>
<td>70.5</td>
<td>16.1</td>
<td>2.66</td>
<td>7.22**</td>
<td>0.59</td>
<td>0.81</td>
<td>0.48</td>
<td>838</td>
<td>0.94</td>
<td>0.09</td>
<td>0.02</td>
<td>LA-ICP-MS 2010</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>SER 5</td>
<td>70.2</td>
<td>16.4</td>
<td>2.58</td>
<td>7.12*</td>
<td>0.62</td>
<td>0.78</td>
<td>0.46</td>
<td>820</td>
<td>1.02</td>
<td>0.09</td>
<td>0.02</td>
<td>LA-ICP-MS 2010</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>SER 7</td>
<td>68.7</td>
<td>16.4</td>
<td>2.69</td>
<td>8.56*</td>
<td>0.68</td>
<td>0.85</td>
<td>0.54</td>
<td>874</td>
<td>0.79</td>
<td>0.10</td>
<td>0.02</td>
<td>LA-ICP-MS 2010</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>G 31</td>
<td>70.5</td>
<td>14.9</td>
<td>3.42</td>
<td>9.35</td>
<td>0.89</td>
<td>0.57</td>
<td>0.48</td>
<td>1250</td>
<td>0.79</td>
<td>0.08</td>
<td>0.15</td>
<td>LA-ICP-MS 2010</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>SER 6</td>
<td>67.0</td>
<td>14.9</td>
<td>3.28</td>
<td>10.49*</td>
<td>0.75</td>
<td>1.09</td>
<td>0.55</td>
<td>1095</td>
<td>0.88</td>
<td>0.10</td>
<td>0.02</td>
<td>LA-ICP-MS 2010</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>G 30</td>
<td>70.4</td>
<td>14.1</td>
<td>3.22</td>
<td>8.96</td>
<td>0.85</td>
<td>0.57</td>
<td>0.49</td>
<td>1350</td>
<td>0.93</td>
<td>0.07</td>
<td>0.14</td>
<td>LA-ICP-MS 2010</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>G 26</td>
<td>70.4</td>
<td>14.6</td>
<td>3.10</td>
<td>8.67</td>
<td>0.89</td>
<td>0.53</td>
<td>0.46</td>
<td>1205</td>
<td>0.85</td>
<td>0.06</td>
<td>0.07</td>
<td>LA-ICP-MS 2010</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>G 29</td>
<td>71.1</td>
<td>13.9</td>
<td>3.26</td>
<td>8.55</td>
<td>0.90</td>
<td>0.56</td>
<td>0.47</td>
<td>1286</td>
<td>0.78</td>
<td>0.07</td>
<td>0.14</td>
<td>LA-ICP-MS 2010</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>G 30</td>
<td>70.4</td>
<td>14.1</td>
<td>3.22</td>
<td>8.96</td>
<td>0.85</td>
<td>0.57</td>
<td>0.49</td>
<td>1350</td>
<td>0.93</td>
<td>0.07</td>
<td>0.14</td>
<td>LA-ICP-MS 2010</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>G 32</td>
<td>69.9</td>
<td>14.1</td>
<td>3.42</td>
<td>9.35</td>
<td>0.89</td>
<td>0.57</td>
<td>0.48</td>
<td>1250</td>
<td>0.79</td>
<td>0.08</td>
<td>0.15</td>
<td>LA-ICP-MS 2010</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>SER 1</td>
<td>71.0</td>
<td>16.3</td>
<td>2.81</td>
<td>7.30**</td>
<td>0.56</td>
<td>0.82</td>
<td>0.47</td>
<td>561</td>
<td>1.00</td>
<td>0.09</td>
<td>0.02</td>
<td>LA-ICP-MS 2010</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>SER 3</td>
<td>68.2</td>
<td>17.1</td>
<td>2.86</td>
<td>8.10*</td>
<td>0.68</td>
<td>0.67</td>
<td>0.46</td>
<td>964</td>
<td>1.01</td>
<td>0.08</td>
<td>0.03</td>
<td>LA-ICP-MS 2010</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>SER 6</td>
<td>67.0</td>
<td>14.9</td>
<td>3.28</td>
<td>10.49*</td>
<td>0.75</td>
<td>1.09</td>
<td>0.55</td>
<td>1095</td>
<td>0.88</td>
<td>0.10</td>
<td>0.02</td>
<td>LA-ICP-MS 2010</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>SER 7</td>
<td>68.7</td>
<td>16.4</td>
<td>2.69</td>
<td>8.56*</td>
<td>0.68</td>
<td>0.85</td>
<td>0.54</td>
<td>874</td>
<td>0.79</td>
<td>0.10</td>
<td>0.02</td>
<td>LA-ICP-MS 2010</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mn-decolourised</td>
<td>SER 12</td>
<td>70.5</td>
<td>16.1</td>
<td>2.66</td>
<td>7.22**</td>
<td>0.59</td>
<td>0.81</td>
<td>0.48</td>
<td>838</td>
<td>0.94</td>
<td>0.09</td>
<td>0.02</td>
<td>LA-ICP-MS 2010</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>SER 5</td>
<td>70.2</td>
<td>16.4</td>
<td>2.58</td>
<td>7.12*</td>
<td>0.62</td>
<td>0.78</td>
<td>0.46</td>
<td>820</td>
<td>1.02</td>
<td>0.09</td>
<td>0.02</td>
<td>LA-ICP-MS 2010</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>SER 7</td>
<td>68.7</td>
<td>16.4</td>
<td>2.69</td>
<td>8.56*</td>
<td>0.68</td>
<td>0.85</td>
<td>0.54</td>
<td>874</td>
<td>0.79</td>
<td>0.10</td>
<td>0.02</td>
<td>LA-ICP-MS 2010</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**APPENDIX B.2.1. Levantine I composition - naturally coloured and Mn-decolourised**
<table>
<thead>
<tr>
<th></th>
<th>wt%</th>
<th>ppm/ wt%</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>SiO2</td>
<td>Na2O</td>
<td>Al2O3</td>
</tr>
<tr>
<td>G 1</td>
<td>71.3</td>
<td>15.2</td>
<td>3.60</td>
</tr>
<tr>
<td>G 2</td>
<td>71.6</td>
<td>15.2</td>
<td>3.53</td>
</tr>
<tr>
<td>G 3</td>
<td>71.6</td>
<td>15.3</td>
<td>3.54</td>
</tr>
<tr>
<td>G 40</td>
<td>66.7</td>
<td>19.4</td>
<td>3.45</td>
</tr>
<tr>
<td>G 61</td>
<td>67.7</td>
<td>18.2</td>
<td>3.53</td>
</tr>
<tr>
<td>G 28</td>
<td>70.6</td>
<td>15.8</td>
<td>3.46</td>
</tr>
</tbody>
</table>

ppm values

<table>
<thead>
<tr>
<th></th>
<th>Fe2O3</th>
<th>TiO2</th>
<th>ZrO2</th>
<th>Cr2O3</th>
<th>HfO2</th>
<th>Nb2O3</th>
<th>Y2O3</th>
<th>La2O3</th>
<th>CeO2</th>
<th>PrO2</th>
<th>Nd2O3</th>
<th>NiO</th>
<th>As2O3</th>
<th>Li2O</th>
<th>Rb2O</th>
<th>BaO</th>
<th>SrO</th>
<th>V2O5</th>
<th>B2O3</th>
</tr>
</thead>
<tbody>
<tr>
<td>G 1</td>
<td>15733</td>
<td>5921</td>
<td>349</td>
<td>108</td>
<td>7</td>
<td>7</td>
<td>11</td>
<td>10</td>
<td>22</td>
<td>3</td>
<td>11</td>
<td>2</td>
<td>6</td>
<td>11</td>
<td>2</td>
<td>6</td>
<td>5</td>
<td>591</td>
<td></td>
</tr>
<tr>
<td>G 2</td>
<td>15333</td>
<td>5887</td>
<td>345</td>
<td>107</td>
<td>7</td>
<td>7</td>
<td>10</td>
<td>10</td>
<td>21</td>
<td>3</td>
<td>11</td>
<td>2</td>
<td>6</td>
<td>5</td>
<td>5</td>
<td>11</td>
<td>6</td>
<td>57</td>
<td></td>
</tr>
<tr>
<td>G 3</td>
<td>14653</td>
<td>5951</td>
<td>362</td>
<td>110</td>
<td>7</td>
<td>7</td>
<td>11</td>
<td>11</td>
<td>22</td>
<td>3</td>
<td>11</td>
<td>10</td>
<td>6</td>
<td>2</td>
<td>6</td>
<td>5</td>
<td>5</td>
<td>141</td>
<td>59</td>
</tr>
<tr>
<td>G 60</td>
<td>16477</td>
<td>5285</td>
<td>318</td>
<td>96</td>
<td>7</td>
<td>7</td>
<td>11</td>
<td>11</td>
<td>24</td>
<td>3</td>
<td>12</td>
<td>3</td>
<td>13</td>
<td>3</td>
<td>3</td>
<td>7</td>
<td>181</td>
<td>495</td>
<td>65</td>
</tr>
<tr>
<td>G 61</td>
<td>15865</td>
<td>5909</td>
<td>377</td>
<td>112</td>
<td>7</td>
<td>7</td>
<td>11</td>
<td>11</td>
<td>24</td>
<td>3</td>
<td>12</td>
<td>3</td>
<td>12</td>
<td>3</td>
<td>3</td>
<td>4</td>
<td>7</td>
<td>174</td>
<td>505</td>
</tr>
<tr>
<td>G 28</td>
<td>15909</td>
<td>5833</td>
<td>327</td>
<td>96</td>
<td>7</td>
<td>7</td>
<td>11</td>
<td>11</td>
<td>23</td>
<td>3</td>
<td>11</td>
<td>11</td>
<td>2</td>
<td>1</td>
<td>6</td>
<td>158</td>
<td>445</td>
<td>59</td>
<td>589</td>
</tr>
</tbody>
</table>

APPENDIX B.2.3. HIT composition
<table>
<thead>
<tr>
<th>wt%</th>
<th>ppm/ wt%</th>
</tr>
</thead>
<tbody>
<tr>
<td>SiO2</td>
<td>Na2O</td>
</tr>
<tr>
<td>Al2O3</td>
<td>CaO</td>
</tr>
<tr>
<td>K2O</td>
<td>MgO</td>
</tr>
<tr>
<td>Fe2O3</td>
<td>P2O5</td>
</tr>
<tr>
<td>Cl</td>
<td>SO3</td>
</tr>
<tr>
<td>TiO2</td>
<td>MnO</td>
</tr>
<tr>
<td>Sb2O3</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>G 84</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>71.7</td>
<td>15.6</td>
<td>1.77</td>
<td>8.25</td>
<td>0.22</td>
<td>0.46</td>
<td>0.34</td>
<td>356</td>
<td>1.05</td>
<td>0.06</td>
<td>0.01</td>
</tr>
<tr>
<td>G 84</td>
<td>70.2</td>
<td>17.2</td>
<td>1.65*</td>
<td>6.96</td>
<td>0.29</td>
<td>0.45</td>
<td>0.35</td>
<td>0.02</td>
<td>1.08</td>
<td>0.27</td>
</tr>
<tr>
<td>SER 28</td>
<td>70.7</td>
<td>18.2</td>
<td>1.94</td>
<td>5.83</td>
<td>0.36</td>
<td>0.33</td>
<td>0.40</td>
<td>927</td>
<td>1.24</td>
<td></td>
</tr>
<tr>
<td>SER 28</td>
<td>69.4</td>
<td>18.5</td>
<td>1.88</td>
<td>5.74</td>
<td>0.30</td>
<td>0.30</td>
<td>0.23</td>
<td>0.02</td>
<td>1.20</td>
<td>0.23</td>
</tr>
<tr>
<td>SER 26</td>
<td>66.9</td>
<td>20.2</td>
<td>2.33</td>
<td>6.70</td>
<td>0.31</td>
<td>0.77</td>
<td>0.37</td>
<td>541</td>
<td>1.14</td>
<td></td>
</tr>
<tr>
<td>SER 27</td>
<td>66.0</td>
<td>19.3</td>
<td>2.33</td>
<td>6.72</td>
<td>0.32</td>
<td>0.62</td>
<td>1.04</td>
<td>1031</td>
<td>1.21</td>
<td></td>
</tr>
<tr>
<td>SER 52</td>
<td>69.8</td>
<td>19.0</td>
<td>2.06</td>
<td>5.15</td>
<td>0.33</td>
<td>0.42</td>
<td>0.37</td>
<td>1.17</td>
<td>0.26</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>ppm values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fe2O3</td>
</tr>
<tr>
<td>ZrO2</td>
</tr>
<tr>
<td>HfO2</td>
</tr>
<tr>
<td>Y2O3</td>
</tr>
<tr>
<td>CeO2</td>
</tr>
<tr>
<td>Nd2O3</td>
</tr>
<tr>
<td>As2O3</td>
</tr>
<tr>
<td>Rb2O</td>
</tr>
<tr>
<td>SrO</td>
</tr>
<tr>
<td>B2O3</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>G 84</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3437</td>
<td>634</td>
<td>61</td>
<td>14</td>
<td>1</td>
<td>2</td>
<td>8</td>
</tr>
<tr>
<td>G 84</td>
<td>4028</td>
<td>621</td>
<td>52</td>
<td>12</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>SER 26</td>
<td>6408</td>
<td>1051</td>
<td>85</td>
<td>22</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>SER 27</td>
<td>10369</td>
<td>910</td>
<td>76</td>
<td>17</td>
<td>2</td>
<td>2</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>ppm values</th>
</tr>
</thead>
<tbody>
<tr>
<td>MnO</td>
</tr>
<tr>
<td>CoO</td>
</tr>
<tr>
<td>ZnO</td>
</tr>
<tr>
<td>PbO</td>
</tr>
</tbody>
</table>

|        | LA-ICP-MS 2010 | EPMA 2013 | LA-ICP-MS 2013 | EPMA 2013 | LA-ICP-MS 2013 |
|--------|----------------|-----------|----------------|-----------|----------------|-----------|
| G 84   |                |           |                |           |                |           |                |           |                |           |
| 132    | 3988           | 1         | 10             | 18        | 10             | 9         | LA-ICP-MS 2010 |
| SER 28 | 140            | 5812      | 1              | 54        | 23             | 107       | 36             | 10        | 14             | 10        | 2201           | LA-ICP-MS 2013 |
| SER 26 | 1587           | 5979      | 4              | 43        | 52             | 16        | 74             | 10        | 14             | 10        | 2201           | LA-ICP-MS 2013 |
| SER 27 | 2656           | 13047     | 380            | 1247      | 55             | 111       | 2201           |           |                |           |                |           |

APPENDIX B.2.4. Sb-decolourised composition
<table>
<thead>
<tr>
<th>wt%</th>
<th>ppm/ wt%</th>
</tr>
</thead>
<tbody>
<tr>
<td>SiO2</td>
<td>Na2O</td>
</tr>
<tr>
<td>G 67</td>
<td>69.8</td>
</tr>
<tr>
<td>G 67</td>
<td>69.6</td>
</tr>
<tr>
<td>SER 14</td>
<td>70.7</td>
</tr>
<tr>
<td>SER 14</td>
<td>68.4</td>
</tr>
<tr>
<td>SER 15(1)</td>
<td>70.3</td>
</tr>
<tr>
<td>SER 15(2)</td>
<td>70.2</td>
</tr>
<tr>
<td>SER 16</td>
<td>69.4</td>
</tr>
<tr>
<td>SER 17(1)</td>
<td>68.4</td>
</tr>
<tr>
<td>SER 17(2)</td>
<td>68.7</td>
</tr>
<tr>
<td>SER 18</td>
<td>70.3</td>
</tr>
<tr>
<td>SER 8</td>
<td>70.3</td>
</tr>
<tr>
<td>PLD 1</td>
<td>69.5</td>
</tr>
</tbody>
</table>

ppm values

<table>
<thead>
<tr>
<th></th>
<th>ppm/ wt%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fe2O3</td>
<td>TiO2</td>
</tr>
<tr>
<td>G 67</td>
<td>5702</td>
</tr>
<tr>
<td>G 67</td>
<td>5460</td>
</tr>
<tr>
<td>SER 14</td>
<td>5960</td>
</tr>
<tr>
<td>SER 15(1)</td>
<td>5813</td>
</tr>
<tr>
<td>SER 16</td>
<td>7146</td>
</tr>
<tr>
<td>SER 17(1)</td>
<td>7369</td>
</tr>
<tr>
<td>SER 17(2)</td>
<td>6691</td>
</tr>
<tr>
<td>SER 18</td>
<td>4625</td>
</tr>
<tr>
<td>SER 8</td>
<td>4028</td>
</tr>
<tr>
<td>PLD 1</td>
<td>4871</td>
</tr>
</tbody>
</table>

APPENDIX B.2.5. Mixed Sb-Mn composition
<table>
<thead>
<tr>
<th>w% / Total</th>
<th>F0</th>
<th>F1</th>
<th>F2</th>
<th>F3</th>
<th>F4</th>
<th>F5</th>
<th>F6</th>
<th>F7</th>
<th>F8</th>
<th>F9</th>
<th>F10</th>
<th>F11</th>
<th>F12</th>
<th>F13</th>
<th>F14</th>
<th>F15</th>
<th>F16</th>
<th>F17</th>
<th>F18</th>
<th>F19</th>
<th>F20</th>
</tr>
</thead>
<tbody>
<tr>
<td>5.52</td>
<td>5.29</td>
<td>2.79</td>
<td>1.22</td>
<td>0.64</td>
<td>0.22</td>
<td>0.06</td>
<td>0.04</td>
<td>0.03</td>
<td>0.02</td>
<td>0.01</td>
<td>0.01</td>
<td>0.01</td>
<td>0.01</td>
<td>0.01</td>
<td>0.01</td>
<td>0.01</td>
<td>0.01</td>
<td>0.01</td>
<td>0.01</td>
<td>0.01</td>
<td></td>
</tr>
<tr>
<td>0.29</td>
<td>0.74</td>
<td>1.22</td>
<td>6.14</td>
<td>3.88</td>
<td>0.28</td>
<td>0.18</td>
<td>0.13</td>
<td>0.09</td>
<td>0.07</td>
<td>0.06</td>
<td>0.05</td>
<td>0.05</td>
<td>0.05</td>
<td>0.05</td>
<td>0.05</td>
<td>0.05</td>
<td>0.05</td>
<td>0.05</td>
<td>0.05</td>
<td>0.05</td>
<td></td>
</tr>
<tr>
<td>0.22</td>
<td>0.06</td>
<td>0.04</td>
<td>0.03</td>
<td>0.02</td>
<td>0.01</td>
<td>0.01</td>
<td>0.01</td>
<td>0.01</td>
<td>0.01</td>
<td>0.01</td>
<td>0.01</td>
<td>0.01</td>
<td>0.01</td>
<td>0.01</td>
<td>0.01</td>
<td>0.01</td>
<td>0.01</td>
<td>0.01</td>
<td>0.01</td>
<td>0.01</td>
<td></td>
</tr>
<tr>
<td>0.06</td>
<td>0.04</td>
<td>0.03</td>
<td>0.02</td>
<td>0.01</td>
<td>0.01</td>
<td>0.01</td>
<td>0.01</td>
<td>0.01</td>
<td>0.01</td>
<td>0.01</td>
<td>0.01</td>
<td>0.01</td>
<td>0.01</td>
<td>0.01</td>
<td>0.01</td>
<td>0.01</td>
<td>0.01</td>
<td>0.01</td>
<td>0.01</td>
<td>0.01</td>
<td></td>
</tr>
<tr>
<td>0.04</td>
<td>0.03</td>
<td>0.02</td>
<td>0.01</td>
<td>0.01</td>
<td>0.01</td>
<td>0.01</td>
<td>0.01</td>
<td>0.01</td>
<td>0.01</td>
<td>0.01</td>
<td>0.01</td>
<td>0.01</td>
<td>0.01</td>
<td>0.01</td>
<td>0.01</td>
<td>0.01</td>
<td>0.01</td>
<td>0.01</td>
<td>0.01</td>
<td>0.01</td>
<td></td>
</tr>
<tr>
<td>0.03</td>
<td>0.01</td>
<td>0.01</td>
<td>0.01</td>
<td>0.01</td>
<td>0.01</td>
<td>0.01</td>
<td>0.01</td>
<td>0.01</td>
<td>0.01</td>
<td>0.01</td>
<td>0.01</td>
<td>0.01</td>
<td>0.01</td>
<td>0.01</td>
<td>0.01</td>
<td>0.01</td>
<td>0.01</td>
<td>0.01</td>
<td>0.01</td>
<td>0.01</td>
<td></td>
</tr>
<tr>
<td>0.01</td>
<td>0.01</td>
<td>0.01</td>
<td>0.01</td>
<td>0.01</td>
<td>0.01</td>
<td>0.01</td>
<td>0.01</td>
<td>0.01</td>
<td>0.01</td>
<td>0.01</td>
<td>0.01</td>
<td>0.01</td>
<td>0.01</td>
<td>0.01</td>
<td>0.01</td>
<td>0.01</td>
<td>0.01</td>
<td>0.01</td>
<td>0.01</td>
<td>0.01</td>
<td></td>
</tr>
<tr>
<td>0.01</td>
<td>0.01</td>
<td>0.01</td>
<td>0.01</td>
<td>0.01</td>
<td>0.01</td>
<td>0.01</td>
<td>0.01</td>
<td>0.01</td>
<td>0.01</td>
<td>0.01</td>
<td>0.01</td>
<td>0.01</td>
<td>0.01</td>
<td>0.01</td>
<td>0.01</td>
<td>0.01</td>
<td>0.01</td>
<td>0.01</td>
<td>0.01</td>
<td>0.01</td>
<td></td>
</tr>
<tr>
<td>0.01</td>
<td>0.01</td>
<td>0.01</td>
<td>0.01</td>
<td>0.01</td>
<td>0.01</td>
<td>0.01</td>
<td>0.01</td>
<td>0.01</td>
<td>0.01</td>
<td>0.01</td>
<td>0.01</td>
<td>0.01</td>
<td>0.01</td>
<td>0.01</td>
<td>0.01</td>
<td>0.01</td>
<td>0.01</td>
<td>0.01</td>
<td>0.01</td>
<td>0.01</td>
<td></td>
</tr>
<tr>
<td>0.01</td>
<td>0.01</td>
<td>0.01</td>
<td>0.01</td>
<td>0.01</td>
<td>0.01</td>
<td>0.01</td>
<td>0.01</td>
<td>0.01</td>
<td>0.01</td>
<td>0.01</td>
<td>0.01</td>
<td>0.01</td>
<td>0.01</td>
<td>0.01</td>
<td>0.01</td>
<td>0.01</td>
<td>0.01</td>
<td>0.01</td>
<td>0.01</td>
<td>0.01</td>
<td></td>
</tr>
<tr>
<td>0.01</td>
<td>0.01</td>
<td>0.01</td>
<td>0.01</td>
<td>0.01</td>
<td>0.01</td>
<td>0.01</td>
<td>0.01</td>
<td>0.01</td>
<td>0.01</td>
<td>0.01</td>
<td>0.01</td>
<td>0.01</td>
<td>0.01</td>
<td>0.01</td>
<td>0.01</td>
<td>0.01</td>
<td>0.01</td>
<td>0.01</td>
<td>0.01</td>
<td>0.01</td>
<td></td>
</tr>
</tbody>
</table>

APPENDIX B.2.5. Sf c. Mn-decoloured glass composition - main group, intermediate sub-group and outliers
<table>
<thead>
<tr>
<th>ppm values</th>
<th>ppm values</th>
</tr>
</thead>
<tbody>
<tr>
<td>MnO</td>
<td>Sb2O3</td>
</tr>
<tr>
<td>G 75</td>
<td>17213</td>
</tr>
<tr>
<td>G 74</td>
<td>15159</td>
</tr>
<tr>
<td>G 52</td>
<td>14355</td>
</tr>
<tr>
<td>G 78</td>
<td>16099</td>
</tr>
<tr>
<td>G 68</td>
<td>15266</td>
</tr>
<tr>
<td>G 72</td>
<td>12069</td>
</tr>
<tr>
<td>G 71</td>
<td>12702</td>
</tr>
<tr>
<td>G 73</td>
<td>12570</td>
</tr>
<tr>
<td>G 77</td>
<td>12752</td>
</tr>
<tr>
<td>G 76</td>
<td>17313</td>
</tr>
<tr>
<td>G 51</td>
<td>17179</td>
</tr>
<tr>
<td>G 53</td>
<td>14405</td>
</tr>
<tr>
<td>G 63</td>
<td>13225</td>
</tr>
<tr>
<td>G 38</td>
<td>15628</td>
</tr>
<tr>
<td>SER 13</td>
<td>13550</td>
</tr>
<tr>
<td>SER 21</td>
<td>13642</td>
</tr>
<tr>
<td>SER 22 (1)</td>
<td>15459</td>
</tr>
<tr>
<td>SER 22 (2)</td>
<td>15121</td>
</tr>
<tr>
<td>SER 4</td>
<td>12981</td>
</tr>
<tr>
<td>SER 37</td>
<td>16880</td>
</tr>
<tr>
<td>SER 43</td>
<td>17473</td>
</tr>
<tr>
<td>SER 32</td>
<td>3892</td>
</tr>
<tr>
<td>SER 33</td>
<td>12471</td>
</tr>
<tr>
<td>SER 34</td>
<td>18050</td>
</tr>
<tr>
<td>ODR 2</td>
<td>12634</td>
</tr>
<tr>
<td>ODR 3</td>
<td>9482</td>
</tr>
<tr>
<td>ODR 4</td>
<td>13030</td>
</tr>
<tr>
<td>ODR 7</td>
<td>11675</td>
</tr>
<tr>
<td>ODR 10</td>
<td>10704</td>
</tr>
<tr>
<td>ODR 13</td>
<td>15667</td>
</tr>
<tr>
<td>ODR 14</td>
<td>17296</td>
</tr>
<tr>
<td>ODR 15</td>
<td>15088</td>
</tr>
<tr>
<td>ODR 16</td>
<td>16446</td>
</tr>
<tr>
<td>ODR 17</td>
<td>15861</td>
</tr>
<tr>
<td>ODR 19</td>
<td>14747</td>
</tr>
<tr>
<td>ODR 21</td>
<td>17571</td>
</tr>
<tr>
<td>ODR 22</td>
<td>13425</td>
</tr>
<tr>
<td>ODR 23</td>
<td>17377</td>
</tr>
<tr>
<td>ODR 24</td>
<td>14773</td>
</tr>
<tr>
<td>ODR 25</td>
<td>10923</td>
</tr>
<tr>
<td>ODR 28</td>
<td>4479</td>
</tr>
<tr>
<td>ODR 29</td>
<td>12261</td>
</tr>
<tr>
<td>ODR 31</td>
<td>11825</td>
</tr>
<tr>
<td>ODR 40</td>
<td>3105</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>wt%</th>
<th>ppm/ wt%</th>
</tr>
</thead>
<tbody>
<tr>
<td>SiO2</td>
<td>Na2O</td>
</tr>
<tr>
<td>Al2O3</td>
<td>CaO</td>
</tr>
<tr>
<td>K2O</td>
<td>MgO</td>
</tr>
<tr>
<td>Fe2O3</td>
<td>P2O5</td>
</tr>
<tr>
<td>Cl</td>
<td>SO3</td>
</tr>
<tr>
<td>TiO2</td>
<td>MnO</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>ppm values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fe2O3</td>
</tr>
<tr>
<td>G 25</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>ppm values</th>
</tr>
</thead>
<tbody>
<tr>
<td>MnO</td>
</tr>
<tr>
<td>G 25</td>
</tr>
<tr>
<td>SER 19</td>
</tr>
</tbody>
</table>

APPENDIX B.2.7. continued (1) 6th c. glass composition
<table>
<thead>
<tr>
<th>ppm values</th>
<th>ZnO</th>
<th>TiO2</th>
<th>Cr2O3</th>
<th>HfO2</th>
<th>Nb2O5</th>
<th>Y2O3</th>
<th>La2O3</th>
<th>CeO2</th>
<th>Pr2O3</th>
<th>Nd2O3</th>
<th>NIO</th>
<th>As2O3</th>
<th>Na2O</th>
<th>Li2O</th>
<th>Rb2O</th>
<th>BaO</th>
<th>SrO</th>
<th>Y2O3</th>
<th>B2O3</th>
</tr>
</thead>
<tbody>
<tr>
<td>ppm values</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ppm values</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**APPENDIX B.2.7. continued (2) 6th c. glass composition - iron-rich sub-group**
<table>
<thead>
<tr>
<th>wt%</th>
<th>SiO2</th>
<th>Na2O</th>
<th>Al2O3</th>
<th>CaO</th>
<th>K2O</th>
<th>MgO</th>
<th>Fe2O3</th>
<th>P2O5</th>
<th>Cl</th>
<th>SO3</th>
<th>TiO2</th>
<th>MnO</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>G42</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>67.3</td>
<td>18.0</td>
<td>2.66</td>
<td>6.91</td>
<td>0.44</td>
<td>0.89</td>
<td>1.42</td>
<td>801</td>
<td>1.03</td>
<td></td>
<td>0.29</td>
<td>0.69</td>
</tr>
<tr>
<td></td>
<td>G64</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>67.4</td>
<td>17.9</td>
<td>2.57</td>
<td>7.34</td>
<td>0.45</td>
<td>0.80</td>
<td>1.34</td>
<td>584</td>
<td>0.94</td>
<td></td>
<td>0.31</td>
<td>0.71</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ppm/ wt%</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ppm values</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fe2O3</td>
<td>TiO2</td>
<td>ZrO2</td>
<td>Cr2O3</td>
<td>HfO2</td>
<td>Nb2O5</td>
<td>Y2O3</td>
<td>La2O3</td>
<td>CeO2</td>
<td>PrO2</td>
<td>Nd2O3</td>
<td>NiO</td>
<td>As2O3</td>
</tr>
<tr>
<td></td>
<td>12008</td>
<td>2851</td>
<td>185</td>
<td>50</td>
<td>4</td>
<td>4</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>3</td>
<td>10</td>
<td>16</td>
</tr>
<tr>
<td></td>
<td>13415</td>
<td>3112</td>
<td>206</td>
<td>54</td>
<td>5</td>
<td>4</td>
<td>11</td>
<td>11</td>
<td>20</td>
<td>2</td>
<td>10</td>
<td>16</td>
</tr>
<tr>
<td>ppm values</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>MnO</td>
<td>Sb2O3</td>
<td>CoO</td>
<td>CuO</td>
<td>ZnO</td>
<td>SnO2</td>
<td>PbO</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>G42</td>
<td>6874</td>
<td>4</td>
<td>12</td>
<td>149</td>
<td>35</td>
<td>20</td>
<td>225</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>G64</td>
<td>7086</td>
<td>4</td>
<td>13</td>
<td>34</td>
<td>20</td>
<td>19</td>
<td>58</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ppm values</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>G42</td>
<td>1236</td>
<td>10</td>
<td></td>
<td>295</td>
<td>1363</td>
<td>28</td>
<td>101</td>
<td>4241</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>G64</td>
<td>1269</td>
<td>7</td>
<td></td>
<td>342</td>
<td>1169</td>
<td>40</td>
<td>93</td>
<td>4014</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ppm values</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**APPENDIX B.2.8. Varia**